

Strömgren survey for Asteroseismology and Galactic Archaeology: let the SAGA begin¹

L. Casagrande ^{2,†}, V. Silva Aguirre ³, D. Stello ⁴, D. Huber ^{5,6}, A.M. Serenelli ⁷, S. Cassisi ⁸,
A. Dotter ², A.P. Milone ², S. Hodgkin ⁹, A.F. Marino ², M.N. Lund ³, A. Pietrinferni ⁸,
M. Asplund ², S. Feltzing ¹⁰, C. Flynn ¹¹, F. Grundahl ³, P.E. Nissen ³, R. Schönrich ^{12,13}
K.J. Schlesinger ² W. Wang ¹⁴

luca.casagrande@anu.edu.au

Received _____; accepted _____

²Research School of Astronomy & Astrophysics, Mount Stromlo Observatory, The Australian National University, ACT 2611, Australia

³Stellar Astrophysics Centre, Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Aarhus C, Denmark

⁴Sydney Institute for Astronomy (SfA), School of Physics, University of Sydney, NSW 2006, Australia

⁵NASA Ames Research Center, Moffett Field, CA 94035, USA

⁶SETI Institute, 189 Bernardo Av., Mountain View, CA 94043, USA

⁷Institute of Space Sciences (IEEC-CSIC), Campus UAB, Fac. Ciències, Torre C5 parell 2, E-08193 Bellaterra, Spain

⁸INAF-Osservatorio Astronomico di Collurania, via Maggini, 64100 Teramo, Italy

⁹Institute of Astronomy, Madingley Road, Cambridge CB3 0HA, UK

¹⁰Lund Observatory, Department of Astronomy & Theoretical Physics, Box 43, SE-22100, Lund, Sweden

¹¹Centre for Astrophysics and Supercomputing, Swinburne University of Technology, VIC 3122 Australia

¹²Department of Astronomy, The Ohio State University, 140 West 18th Ave., Columbus, OH 43210-1173, USA; Hubble Fellow

¹³Rudolf-Peierls Centre for Theoretical Physics, University of Oxford, 1 Keble Road, OX1 3NP, Oxford, United Kingdom

¹⁴National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China

[†]Stromlo Fellow

To appear in The Astrophysical Journal

ABSTRACT

Asteroseismology has the capability of precisely determining stellar properties which would otherwise be inaccessible, such as radii, masses and thus ages of stars. When coupling this information with classical determinations of stellar parameters, such as metallicities, effective temperatures and angular diameters, powerful new diagnostics for Galactic studies can be obtained. The ongoing Strömgren survey for Asteroseismology and Galactic Archaeology (SAGA) has the goal of transforming the *Kepler* field into a new benchmark for Galactic studies, similarly to the solar neighborhood. Here we present first results from a stripe centred at Galactic longitude 74° and covering latitude from about 8° to 20° , which includes almost 1000 K-giants with seismic information and the benchmark open cluster NGC 6819. We describe the coupling of classical and seismic parameters, the accuracy as well as the caveats of the derived effective temperatures, metallicities, distances, surface gravities, masses, and radii. Confidence in the achieved precision is corroborated by the detection of the first and secondary clump in a population of field stars with a ratio of 2 to 1, and by the negligible scatter in the seismic distances among NGC 6819 member stars. An assessment of the reliability of stellar parameters in the Kepler Input Catalogue is also performed, and the impact of our results for population studies in the Milky Way is discussed, along with the importance of an all-sky Strömgren survey.

Subject headings: Galaxy: stellar content – stars: abundances – stars: distances – stars: fundamental parameters – stars: oscillations – surveys – techniques: photometric

1. Introduction

The study of a sizeable number of individual stars in the Milky Way enables us to directly access different phases of its formation and evolution, in a fashion which is still hardly achievable for external galaxies. For obvious reasons, stars in the vicinity of the Sun have been preferred targets for this purpose, starting from the very first (e.g., Gliese 1957; Wallerstein 1962; van den Bergh 1962; Eggen et al. 1962) until the most recent photometric and spectroscopic investigations of the Milky Way, for which *Hipparcos* astrometric distances are also available out to $\simeq 100$ pc (e.g., Nordström et al. 2004; Reddy et al. 2006; Feltzing & Bensby 2008; Casagrande et al. 2011; Adibekyan et al. 2013; Bensby et al. 2013). Properties of stars in the solar neighborhood, in particular ages and metallicities, are still the main constraint for Galactic chemo(dynamical) models (e.g., Cescutti et al. 2007; Schönrich & Binney 2009; Kobayashi & Nakasato 2011; Minchev et al. 2012; Wang & Zhao 2013) and provide important clues to understanding the main processes at play in galaxy formation and evolution (e.g., Pilkington et al. 2012; Bird et al. 2013).

This sort of study is now fostered by a number of spectroscopic and photometric surveys, targeting different and fainter components of the Milky Way (e.g., “RAVE” Steinmetz et al. 2006; “SDSS-SEGUE” Yanny et al. 2009; “SDSS-APOGEE” Ahn et al. 2013; “VVV” Minniti et al. 2010; “Gaia-ESO” Gilmore et al. 2012; “GALAH” Freeman 2013), although astrometric distances for the targets in these surveys will not be available until the *Gaia* spacecraft releases its data (Lindgren & Perryman 1996; Perryman et al. 2001). A common feature of all past and current stellar surveys is that while it is relatively straightforward to derive some sort of information on the chemical composition of the

¹Based on observations made with the Isaac Newton Telescope operated on the island of La Palma by the Isaac Newton Group in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias.

targets observed (and in many cases even detailed abundances), that is not the case when it comes to masses, radii, distances and, in particular, ages. Even when accurate astrometric distances are available to allow comparison of stars with isochrones, the derived ages are still highly uncertain, and statistical techniques are required to avoid biases (e.g., Pont & Eyer 2004; Jørgensen & Lindegren 2005). Furthermore, isochrone dating is meaningful only for stars in the turnoff and subgiant phase, where stars of different ages are clearly separated on the HR diagram. This is in contrast, for example, to stars on the red giant branch, where isochrones with vastly different ages can fit equally well observational constraints such as effective temperatures, metallicities and surface gravities within their errors (e.g., Soderblom 2010, for a review). Thus, alternative ways to precisely determine masses and radii of stars are the only way forward.

By measuring oscillation frequencies in stars, asteroseismology allows us to determine fundamental physical quantities, in particular masses and radii, which otherwise would be inaccessible in single field stars, and which can be used to obtain information on stellar distances and ages (e.g., Chaplin & Miglio 2013, for a review). Individual frequencies can yield an accuracy of just a few percent on those parameters but their exploitation is more demanding, both observationally and theoretically (Silva Aguirre et al. 2013). Global asteroseismic observables (see Section 3.5) on the contrary are easier to detect and analyze, yet able to provide the aforementioned parameters for a large number of stars with an accuracy that is still much better than achievable by isochrone fitting in the traditional sense. Thanks to space-borne missions such as *CoRoT* (Baglin & Fridlund 2006) and *Kepler* (Gilliland et al. 2010) average oscillation frequencies are now robustly detected in more than 500 main-sequence and subgiant stars, and over 13,000 giants (e.g., De Ridder et al. 2009; Verner et al. 2011; Stello et al. 2013). Asteroseismology is thus emerging as a new tool for studying stellar populations, and initial investigations in this direction have already been done (Chaplin et al. 2011; Miglio et al. 2013b). However, until now asteroseismic studies of

stellar populations had only coarse information on “classical ” stellar parameters such as T_{eff} and $[\text{Fe}/\text{H}]$. Coupling classical parameters with seismic information not only improves the seismic masses and ages obtained for stars (Lebreton & Montalbán 2009; Chaplin et al. 2014), but also allows us to address important questions in stellar and Galactic evolution.

To fully harvest the potential that asteroseismology brings to these studies, classical stellar parameters are vital, yet unavailable for a large sample of stars with detected oscillations. The main purpose of the Kepler Input Catalog (KIC, Brown et al. 2011) was to separate dwarfs from giants, and it is therefore inadequate for high precision stellar and Galactic studies due to significant biases in its stellar parameters (e.g., Molenda-Żakowicz et al. 2011; Pinsonneault et al. 2012; Thygesen et al. 2012). APOGEE will eventually provide parameters for thousands of *Kepler* giants, and similarly the Gaia-ESO Survey and GALAH for the *CoRoT* fields. The advantages of the spectroscopic surveys are obvious, yet photometry still offers a powerful and complementary alternative.

Here, we present the first results from the ongoing Strömgren survey for Asteroseismology and Galactic Archaeology (SAGA) in the *Kepler* field. The goals of our photometric survey are manifold. First, the Strömgren system was envisaged with the ultimate purpose of studying Galactic stellar populations, and designed to provide reliable stellar parameters, in particular metallicities (Strömgren 1963, 1987). Thus, even compared to multi-fiber spectroscopy, wide-field Strömgren imaging is very efficient. It also has the advantage that no pre-selection is made on targets: all stars that fall in a given brightness regime across the instrument field of view will be observed. This greatly simplifies the selection function, which in our case is essentially dictated by the *Kepler* satellite (e.g., Batalha et al. 2010; Farmer et al. 2013). Further, relatively faint magnitudes can be probed at high precision even on a small-class telescope, making it possible to readily derive metallicities over a large magnitude range. The *Kepler* seismic sample presented in this work can thus be used

as reference e.g. for assessing the accuracy at which stellar parameters can be obtained for stars having only photometric measurements, such as the planet host stars we observe in SAGA. At the same time, the sensitivity of Strömgren colors to metallicity, coupled with seismic ages, help immensely to calibrate other metallicity and age dating techniques, thus creating powerful new tools to study more remote Galactic populations than previously possible. Bearing in mind the expected precision at which *Gaia* will deliver astrophysical parameters for stars of different brightness (Liu et al. 2012), the above science case highlight the importance of having an all-sky Strömgren survey going fainter than any of the current large spectroscopic surveys (Wang et al. 2014).

The SAGA survey also represents a natural extension of the Geneva Copenhagen Survey (GCS, Nordström et al. 2004), the only all-sky Strömgren survey currently available, and a benchmark for Galactic studies. Similar to our latest revision of the GCS (Casagrande et al. 2011), we combine Strömgren metallicities with broad-band photometry to obtain effective temperatures (T_{eff}) and metallicities ($[\text{Fe}/\text{H}]$) for all our targets via the Infrared Flux Method (IRFM). This facilitates the task of placing SAGA and GCS on the same scale. However, there are marked differences between the two surveys: the GCS is an all-sky, shallow survey limited to main-sequence and subgiant stars closer than $\simeq 100$ pc (40 pc volume limited). The *Kepler* targets observed by SAGA are primarily giants located between $\simeq 1$ and $\simeq 6$ kpc in a specific region of the Galactic disk (Figures 1 and 2). The use of giants as probes of Galactic Archaeology is possible since it is relatively straightforward to derive ages for these stars once classical stellar parameters are coupled with asteroseismology. This was not the case for the GCS, where isochrone fitting was used, and thus limited to main-sequence and subgiant stars with known astrometric distances. On the other hand, stars in the GCS have kinematic information, which is not available for the SAGA targets. The different distance ranges sampled by the GCS and SAGA makes them complementary: the stellar properties measured within the solar neighborhood

in the former survey can be dynamically stretched across several kpc using kinematics. In contrast, the larger distance range sampled by the giants in SAGA provides *in situ* measurements of various stellar properties over $\simeq 5$ kpc.

In this paper we present the observing strategy and data reduction of the Strömgren survey. After cross-matching this dataset with stars in the *Kepler* field with seismic information, we derive classical and seismic stellar parameters for almost 1,000 targets. Our approach is characterized by the powerful combination of classical and seismic parameters, to our knowledge the first of this kind, and a careful treatment of the errors, allowing us to derive self-consistent effective temperatures, distances, masses and radii with a typical precision of a few percent, in addition to metallicities as we discuss in more detail later. With these parameters in hand, stellar ages are a straightforward by-product, although more caution must be used: we leave their estimation to a subsequent publication.

2. The Strömgren survey

The *uvby* photometric system (Strömgren 1963) is designed for the determination of basic stellar atmospheric parameters through the color indices $(b - y)$, $m_1 = (v - b) - (b - y)$ and $c_1 = (u - v) - (v - b)$. The y magnitude is defined to be essentially the same as Johnson V for stars other than M-type, and the color $(b - y)$ is relatively unaffected by line blanketing and thus well suited for measuring effective temperatures (although in this study we will determine T_{eff} in a more fundamental way, by using broad-band photometry in the IRFM, see Section 3.1). The m_1 index is designed to measure the depression owing to metal lines around 4100 Å (v band), and hence is suitable to infer the metallicity of a variety of stars. Finally, the c_1 index is designed to evaluate the Balmer discontinuity, which is a temperature indicator for B- and A-type stars and a surface gravity indicator for late-type stars, though for stars with lower or comparable temperature than the Sun it also

carries metallicity information (see e.g., Bessell 2005; Önehag et al. 2009; Árnadóttir et al. 2010, and references therein).

2.1. Observations and data reduction

Intermediate-band Strömgren *uvby* photometry was obtained during seven nights with the Wide Field Camera (WFC) on the 2.5-m Isaac Newton Telescope (INT) on La Palma. The camera comprises four $2k \times 4k$ thinned EEV CCDs; the coverage of each of the chips is 22.8×11.4 arcmin for a total field of view of 34×34 arcmin. Pixel size is 13.5 microns, corresponding to 0.33 arcsec/pixel, thus making the instrument ideal for wide field optical imaging surveys (e.g., Drew et al. 2005; Groot et al. 2009; Greiss et al. 2012).

Of the seven nights awarded during period 2012A, only four provided useful data due to bad weather on the other nights. Typical seeing during the four good nights was about 1.1 arcsec, implying a typical FWHM of the stellar PSF of 3–4 pixels.

Strömgren standard stars were chosen from the list of Schuster & Nissen (1988), which is carefully tied to the system used by Olsen (1983) and underlying the GCS used for our previous investigation of stellar properties in the Galactic disk (Casagrande et al. 2011). We use secondary rather than primary Strömgren standards as the latter are too bright to observe with a 2.5-m telescope. Throughout each of the four photometric nights 10 standard stars were usually observed multiple times over a large span of magnitude and color indices, and at different elevations in the sky, bracketing pointings on the *Kepler* field both in airmass and time.

A stripe across the *Kepler* field was observed, covering Galactic latitude $7.6^\circ < b < 19.9^\circ$ and centred at Galactic longitude $l = 74^\circ$. About 60% of the pointings were observed more than once on at least two different photometric nights. We chose a tiling strategy with

an overlap of $\simeq 3$ to $\simeq 10$ arcsec between different pointings over the *Kepler* field, thus allowing to check that photometric zero-points are constant over the observed region. This strategy allows us to uniformly sample the Galactic disk, as encompassed by the field of view of *Kepler*. The lower limit on b is set to avoid regions too close to the plane, where crowding and reddening make it more difficult to use photometric data. The choice of the Galactic longitude upon which our stripe is centered was dictated by the fact that while this region is only moderately affected by dust and obscuration, it also includes the open cluster NGC 6819, which provides a useful benchmark, as discussed later.

The purpose of the SAGA survey is to obtain accurate Strömgren photometry for stars in the magnitude range $10 \lesssim y \lesssim 14$, where *Kepler* is able to detect oscillations in most red giant stars (e.g., Huber et al. 2011). For science pointings, a typical observing sequence comprised one short ($\simeq 5 - 10$ sec) and one long ($30 - 60$ sec) exposure in vby , and two short ($\simeq 30$ sec) and one long ($\simeq 120$ sec) in u , after which a 45 arcsec dither was applied and the above cycle repeated. With this strategy we are able to achieve photometric errors < 0.03 mag in all bands over the magnitude range of interest (see later Figure 4), which is the accuracy needed to obtain robust parameters from Strömgren indices (e.g., Calamida et al. 2007). However, useful stellar properties can still be derived down to 16th magnitude, a regime important for planet-candidate host stars (Batalha et al. 2013; Plavchan et al. 2014).

The images of the *Kepler* field and the standard stars were pre-processed with the Wide Field Survey Pipeline provided by the Cambridge Astronomical Survey Unit (Irwin & Lewis 2001). The operations applied to the images were de-biasing, trimming, flat-fielding and correction for non-linearity.

2.2. Standard stars: photometric calibration

Aperture photometry for standard stars was obtained with the task PHOT within the IRAF² DAOPHOT package. For each star we explored different sizes of the aperture, ranging from 5 to 20 pixels, and found a value of 15 to be optimal. This roughly corresponds to $4\text{--}5 \times \text{FWHM}$ of the typical stellar PSF, and it is ideal for well isolated standards as it is in our case (e.g., Massey & Davis 1992). In order to transform instrumental (inst) into standard magnitudes we adopted the following equation for each of the Strömgren filters ($i = u, v, b, y$)

$$m_{inst,i} = m_i + \epsilon_{1,i}X + \epsilon_{2,i}(m_v - m_y) + \epsilon_{3,i}T + \epsilon_{4,i}, \quad (1)$$

where X and T denote the airmass and time of that CCD exposure, and $m_v - m_y$ is the color of the standard system (e.g., Harris et al. 1981; Grundahl et al. 2002). The terms $\epsilon_{1,i} \dots \epsilon_{4,i}$ were determined individually for each photometric night; cross checks for stars in common observed over different nights confirm these terms are stable to better than 0.01 mag in each band. We found the $\epsilon_{3,i}$ time-term to be significant in u and v , while essentially negligible in b and y . For the sake of our discussion, Equation 1 can be rewritten highlighting only the color term

$$m_{inst,i} = m_i + \epsilon_{2,i}(m_v - m_y) + k_i, \quad (2)$$

where k_i now includes all previous airmass, time and zero-point terms.

As customary with CCD photometry, the transformation to the standard system is done using individual magnitudes rather than Strömgren indices, since each filter is observed separately and hence with a time delay. This is in contrast to four-channel

²IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA) under cooperative agreement with the National Science Foundation.

photometry where observations for all four filters are obtained at the same time, also allowing observations during non photometric nights (e.g., Olsen 1983; Schuster & Nissen 1988; Meléndez et al. 2010). Calibrating upon individual magnitudes has the advantage that we need not to worry that observations through the different filters are obtained at different airmasses for each standard star. Figure 3 shows the residual between our photometry and the standard stars: excellent agreement is obtained in all four filters with small scatter and no obvious trends as function of $(v - y)$. The same check using other color combinations also shows no trends.

2.3. Science stars: photometric calibration

Aperture photometry was done on each of the science images separately. A dedicated suite of scripts has been developed for this purpose, as described below. Coordinate lists for the images in each band were created using the IRAF task DAOFIND. Aperture photometry was done with apertures ranging from 5 to 20 pixels in steps of 1 pixel. Flux and photometric errors (the `merr` output in PHOT, essentially determined from photon statistics) of each source were extracted at all selected apertures. For each image we searched for the brightest stars above a predefined instrumental magnitude, having `merr` < 0.015 mag and separated from any other detected source by at least twice the maximum aperture³. An iterative scheme was employed to move the brightness threshold to fainter magnitudes if less than 10 such stars were identified. These stars were then used to compute the curve-of-growth, which was found to remain essentially constant for apertures larger than 15 pixels. The aperture correction was then computed for each frame as the median of the flux ratio measured in an aperture of 15 and 5 pixels, using a 2.6σ clipping to remove

³More precisely, by twice the annulus plus dannulus as defined in DAOPHOT.

outliers. The mean absolute deviation was used to define σ , which together with the median described above provides robust statistics on our definition of the aperture correction. In this way, we also determined for each magnitude the systematic error stemming from the uncertainty σ in the aperture correction. This procedure was run in an iterative mode, by checking in each frame the position of bright stars on the CCDs and the resulting curve-of-growth. In all instances, results were found to be robust, with no need for further human intervention, thus making it possible to run the entire procedure in batch mode. For each frame, astrometric solutions were computed using the “World Coordinate System” (WCS) from the image header and correcting for field distortion. By cross-matching the position of several of the brightest targets against 2MASS, we conclude the astrometric precision for our coordinates is $0.2 - 0.3$ arcsec⁴. In very few cases (less than 1%) the astrometric solutions were found to differ from 2MASS coordinates with trends depending on the X and Y position on the CCD; those images were excluded from further analysis. For each object identified in each frame, the **RA** and **dec** distance with respect to all other objects identified in subsequent frames and filters was computed: the vast majority of distances cluster into an ellipse of axis 0.4 arcsec in **RA** and 0.3 arcsec in **dec**, which is thus the typical accuracy at which a given object is identified in different frames and filters. This search ellipse was used to match sources in different bands and frames throughout the remainder of the data reduction.

By matching sources in different filters, we are thus able to apply the photometric calibration to the standard system. Notice though, Equation 2 depends on the standard color $m_v - m_y$ which for science targets is not known beforehand. Therefore, we first solved

⁴See also <http://www.ast.cam.ac.uk/~wfcsur/technical/astrometry/>

for m_v and m_y

$$\begin{pmatrix} m_v \\ m_y \end{pmatrix} = \begin{pmatrix} 1 + \epsilon_{2,v} & -\epsilon_{2,v} \\ \epsilon_{2,y} & 1 - \epsilon_{2,y} \end{pmatrix}^{-1} \begin{pmatrix} m_{inst,v} - k_v \\ m_{inst,y} - k_y \end{pmatrix} \quad (3)$$

such that Equation 2 could be applied to m_u and m_b afterwards. For each night, calibrated photometry for each frame in a given filter was cross-matched for stars in common with all other frames in the same filter. We then calculated the median offset with respect to all other images for each frame; zero-point differences were on average a few millimag (thus confirming the stability of our measurements on photometric nights), apart from occasional offsets spurring to several hundredths (or more) of a magnitude. The median is essentially unaffected by the presence of strong outliers and an iterative scheme was employed to bring all frames to exactly the same zero-point, whichever of the following conditions was first satisfied: an average median offset with respect to all other frames in the same filter and in the same night reached below 0.005 mag or if we reached at least 7 iterations. This second condition was chosen to avoid the rare cases when the zero-point correction oscillates just above the 0.005 mag threshold, since convergence within 0.01 mag is always reached within 3 or 4 iterations at most. This zero-point shift for each frame was included as a systematic uncertainty in all the photometric values of that given frame. Since Equations 2 and 3 depend on the standard $m_v - m_y$ color, those were reapplied after correcting for the zero-points determined above.

The photometric error associated with each measurement was derived from the sum of squared residuals stemming from photon statistics, aperture correction uncertainty, and the zero-point shifts described above. If more than one measurement was available, then the weighted average (using the above photometric error as weight) was used and the standard deviation taken as measurement error. Based on these global photometric errors, we define fiducials for selecting stars with the most reliable photometry; those ridge-lines are shown in Figure 4. A star is flagged to have good photometry only if the errors in all four bands

fall below those ridge-lines.

Since we are interested in determining *uvby* for all stars, we took *u* band measurements (our faintest band), and searched for matches in all other filters. The coordinate of each object having Strömgren magnitudes was determined by computing the average coordinate from *uvby* bands, using the standard deviation as the uncertainty. The final catalogue contains 29,521 sources with *uvby* measurements (all shown in Figure 4). Changing the matching criterion to a circular search of radius 1 arcsec returns essentially the same number of objects (29,496).

2.4. Comparison with other Strömgren studies

The only all-sky Strömgren survey is the GCS, which is largely based on the extensive work of Olsen (1983, 1984, 1994a,b) upon which we ought to calibrate. Most of the stars in the GCS are brighter than our saturation limit and are sparsely distributed across the entire sky, resulting in no object in common with our observations. However, we can easily verify if our observations follow the mean loci of good Strömgren photometry in the Olsen system. In the left panel of Figure 5 we plot our measurements in the c_1 vs $(b - y)$ plane, which discriminates between dwarfs and giants (e.g., Faria et al. 2007; Adén et al. 2009). Overplotted is the fiducial dwarf sequence from Olsen (1984) which is well matched by our stars⁵. Because of the relatively bright magnitude range we sample, most of the late type stars are actually giants (cf. left panels in Figure 9, where most of the stars in the bright magnitude range encompassed by dotted lines are in fact giants). Our sample is spread

⁵Fiducials for different metallicities have recently been obtained by Árnadóttir et al. (2010); here we use that of Olsen (1984) for the sake of comparing directly with the original system.

across several degrees in Galactic latitude, where reddening varies from a few hundredths to over a tenth of a magnitude (see Section 3.3). In the central panel we thus use the virtually reddening-free indices $[c_1] = c_1 - 0.2(b - y)$ and $[m_1] = m_1 + 0.3(b - y)$ (e.g., Strömgren 1966; Crawford 1975; Olsen 1984). It is clear that cool dwarfs are separated from giants and that there are a few cool M giants in our sample. For reference, in the right panel we also plot all dwarfs and subgiants from the GCS (which were observed by Olsen), a number of Red Giant Branch (RGB) stars from globular clusters of different metallicities (Grundahl et al. 1998, 2000, 2002, all standardized to the Olsen system), and our own observations of the open cluster NGC 6819 in the *Kepler* field. Again, dwarf stars follow the Olsen’s fiducial, while giants define upper sequences according to their metallicities.

3. Determination of stellar parameters for *Kepler* targets

The purpose of the SAGA survey is to uniformly observe all stars across the *Kepler* field down to V of 15th to 16th magnitude, independently of whether or not they have seismic information. We cross-match all stars with measured Strömgren photometry from the previous Section with all seismic targets in the *Kepler* field of view, i.e. $\simeq 15,000$ giants from the *Kepler* Asteroseismic Science Consortium (KASC) (Stello et al. 2013; Huber et al. 2014) and over 500 dwarfs (Chaplin et al. 2014). We detect about 95% of the seismic targets falling in the region sampled by SAGA so far, totaling 1,010 targets (29 dwarfs and 981 giants). Further cross-matching of the sample with optical and infrared broad-band photometry (for the sake of the IRFM, see Section 3.1) and seismic analysis reduce the sample for which we determine full parameters to 989 stars, implying a completeness of 93% for our final catalogue. Most of the stars in our sample are giants (see also Figure 17), but the procedure we adopt for determining parameters is the same whether a star is a dwarf or a giant (apart from the metallicity calibration, see Section 3.2).

Multi-band photometry of stars in the *Kepler* field allows us to choose the most appropriate set of filters for each of the stellar parameters we wish to determine. One of the key advantages of our approach is that we use seismic information to improve upon the determination of photometric quantities. All parameters described in the following are derived iteratively and in a fully self-consistent manner, following the procedure first presented in Silva Aguirre et al. (2011, 2012) and briefly summarized here. Details on each step are described in the relevant subsections.

Broad-band optical and infrared photometry is used to obtain effective temperatures (T_{eff}), bolometric fluxes (\mathcal{F}_{Bol}) and angular diameters (θ) of each star via the IRFM (Section 3.1). This method depends weakly on the metallicity and surface gravity of a star, rendering it ideal for breaking the degeneracy among these parameters, which instead seriously affects spectroscopic methods (e.g., Alonso et al. 1996; Casagrande et al. 2006). However, being a photometric technique, reddening must be properly taken into account. For each star in our sample, we first take the color excess $E(B - V)$ and $\log g$ from the Kepler Input Catalogue (Brown et al. 2011), while keeping metallicity fixed at $[\text{Fe}/\text{H}] = -0.2$, a value assumed to be roughly representative of the *Kepler* field (e.g., Silva Aguirre et al. 2011; Pinsonneault et al. 2012; Chaplin et al. 2014). These parameters are used as a starting point, but all our solutions converge independently of the initial choice. The effective temperature is derived using the IRFM with these initial $\log g$, $[\text{Fe}/\text{H}]$ and $E(B - V)$. This T_{eff} is then fed into an asteroseismic Bayesian scheme to obtain the mass and the radius of each star (Section 3.5). Scaling θ with the asteroseismic radius, we compute the distance (Silva Aguirre et al. 2012). Using empirically calibrated, three dimensional Galactic extinction models (Section 3.3) this distance is used to derive a new $E(B - V)$, which is then used to deredden the *uvby* photometry and derive Strömgren metallicities (Section 3.2). The above series of steps defines one iteration, and the updated set of $E(B - V)$, $\log g$ and $[\text{Fe}/\text{H}]$ determined at its completion is fed into the IRFM anew, and the procedure outlined above repeated until

convergence is reached in all parameters: this was achieved within three iterations.

We note that in addition to our Strömgren photometry (used exclusively for deriving $[\text{Fe}/\text{H}]$), three broad-band systems are used in the IRFM: this implies three slightly different sets of T_{eff} , \mathcal{F}_{Bol} and θ . Therefore, three sets of seismic parameters, distances and thus reddening estimates (and $[\text{Fe}/\text{H}]$) are obtained even if the same reddening map is used. Within a given map, all these differences are relatively small.

Altogether we explore the use of three different broad-band photometric systems and three reddening maps for a total of 9 different self-consistent combinations of parameters. The effect of adopting different stellar models and pipelines for the seismic analysis has also been investigated. By comparing these values, we are able to obtain realistic error bars (Section 3.7) as well as robust final parameters (Section 3.8). A flow chart illustrating the entire procedure is shown in Figure 6; in the following subsections we describe each step in detail, focusing first on the derivation of classical parameters and turning then to the asteroseismic analysis.

We next discuss the rationale behind our choice of using different approaches to determine different stellar parameters, instead of for example implementing a global minimization scheme to match all photometric and seismic observables simultaneously. As described in the relevant subsections, effective temperatures, angular diameters, metallicities and reddening are determined using well-established and almost entirely empirical techniques. These empirically determined quantities are then fed into a Bayesian scheme built upon a grid of theoretical models. Extending this Bayesian scheme to include observed photometric indices, would make the determination of classical stellar parameters entirely dependent on theoretical models. In addition, it would carry uncertainties related on the standardization of synthetic colors (which are usually small) as well as on model flux deficiencies and/or uncertainties. The latter can be non-negligible in intermediate band

filters, as well as towards the blue and ultraviolet wavelengths (Casagrande & Vandenberg 2014). In our case, the dependence on synthetic flux is minimized by the multi broad-band photometry, as well as by the use of fully empirical calibrations in the intermediate band Strömgren system.

3.1. Effective Temperatures and angular diameters

Effective temperatures are derived using the IRFM described in Casagrande et al. (2010). This technique uses multi-band optical and infrared photometry to recover the bolometric and infrared flux of each star, from which its T_{eff} and θ can be computed. In our original formulation, implementing either Tycho2–2MASS or Johnson-(Cousins)–2MASS photometry, the zero point of the effective temperature scale is secured via solar twins, and the reliability of the angular diameters checked against dwarf and subgiant stars with interferometric measurements. This technique has already been used in a number of *Kepler* investigations (e.g., Silva Aguirre et al. 2011, 2012; Huber et al. 2012; Chaplin et al. 2014) and its accuracy now extended and validated also for giants (Casagrande et al. 2014).

Here we implement the IRFM with three different optical systems (KIC *griz*, Johnson *BV* and Sloan *g'r'i'*), while in all instances 2MASS photometry is used in the infrared. While we defer more details on the quality of 2MASS photometry to Section 3.6, here it suffices to recall its excellent accuracy, with both median and mean errors of only 0.02 mag in all three infrared bands. The implementation of the IRFM in the KIC *griz*–2MASS system is anchored to Tycho2–2MASS, requiring that on average the parameters derived in the two cases agree. The KIC magnitudes are affected by color dependent zero-point offsets which are corrected according to Pinsonneault et al. (2012). Fortunately, the AAVSO Photometric All-Sky Survey (APASS) offers an independent source of photometry to check the soundness of the results obtained using the KIC corrected photometry. We use the latest

APASS Data Release (DR7) which covers 97% of the sky in the magnitude range 10 to 17 in the Johnson BV and Sloan $g'r'i'$ filters. The advantage of implementing three different optical combinations in the IRFM is that the results in the Johnson–2MASS system are well standardized and much tested (Casagrande et al. 2010, 2012), while Sloan–2MASS allows us to check the consistency of the results obtained with the corrected KIC photometry plus 2MASS. The comparison among the three systems also helps us to assess the reliability of the results and the overall error budget (see also Section 3.7 and Figure 10). We stress here that optical broad-band photometry is preferable to Strömgren for the IRFM, since comparably little flux is encompassed within the intermediate band-width of the Strömgren system (which is anyway almost entirely covered by our broad-band photometry). Furthermore, Strömgren bands are designed to be more sensitive to both $\log g$ and $[\text{Fe}/\text{H}]$, which would make the IRFM estimates more dependent upon those parameters.

3.2. Metallicities

Strömgren photometry is designed to effectively distinguish between dwarfs and giants and to provide reliable metallicity estimates in late type stars (e.g., Önehag et al. 2009; Árnadóttir et al. 2010, and references therein). Much of the past literature has focused on metallicity calibrations for dwarf stars (e.g., Olsen 1984; Schuster & Nissen 1989; Haywood 2002; Nordström et al. 2004; Twarog et al. 2007; Casagrande et al. 2011) while considerably less attention has been devoted to giants. Most of the studies involving giants focused on the metal-poor regime (e.g. Faria et al. 2007; Calamida et al. 2007; Aden 2011) and the only calibrations extending up to the solar metallicity are essentially those of Grebel & Richtler (1992) and Hilker (2000).

We have already derived a metallicity calibration for dwarfs and subgiants in Casagrande et al. (2011) and here we extend it to giants. All calibrating stars in the

metal poor regime have Strömgren photometry from the extensive work of Grundahl et al. (1998, 2000, 2002), from which we cross-match stars with measured $[\text{Fe}/\text{H}]$ in the following monometallic⁶ globular clusters: NGC 6341 (M92, $[\text{Fe}/\text{H}] = -2.64$ Roederer & Sneden 2011), NGC 6397 ($[\text{Fe}/\text{H}] = -2.10$ Lind et al. 2011), NGC 6205 (M13, $[\text{Fe}/\text{H}] = -1.58$ Sneden et al. 2004), NGC 288 ($[\text{Fe}/\text{H}] = -1.22$ Carretta et al. 2009), NGC 6838 (M71, $[\text{Fe}/\text{H}] = -0.82$ Carretta et al. 2009), NGC 104 (47 Tuc, $[\text{Fe}/\text{H}] = -0.75$ Carretta et al. 2009). In the metal-rich regime we use our own Strömgren photometry, with single member, seismic giants in the solar metallicity open cluster NGC 6819 (Stello et al. 2011), plus seven field giants we have in common with the spectroscopic sample of Thygesen et al. (2012). Altogether our Strömgren metallicity sample of giants comprises 199 stars. We take reddening values for stars in globular clusters from the latest version of the Harris (1996) catalogue⁷. This provides robust estimates, given that the majority of them has very low $E(B - V)$, and the absence of any substantial differential reddening (even for NGC 6397 and NGC 6838 which suffer from somewhat higher extinction, see Milone et al. 2012a). For NGC 6819 we adopted $E(B - V) = 0.14$ while for the remaining field giants reddening is estimated in much the same way as for our other *Kepler* targets (see Section 3.3).

We tested different functional forms relating Strömgren colors⁸ to $[\text{Fe}/\text{H}]$. Instead of including all possible combinations of indices in some high-order polynomial, we started with a simple multi-linear dependence on the three Strömgren indices, and introduced

⁶For M92, Roederer & Sneden (2011) found that red giants are chemically homogeneous at the level of $0.07 - 0.16$ dex, although large non-homogeneity in neutron capture elements are disputed (Cohen 2011).

⁷<http://www.physics.mcmaster.ca/Globular.html>

⁸In the following we will refer to c_1 , m_1 and $b - y$ with the implicit understanding that when deriving metallicities these indices must first be dereddened.

mixed and higher order terms after verifying that they improved the residuals. The form adopted is the following:

$$[\text{Fe}/\text{H}] = -9.037(b - y) + 4.875c_1 + 17.187m_1 + 3.672(b - y)c_1 - 9.430(b - y)m_1 \\ - 12.303c_1^2 - 17.405m_1^2 + 6.159(b - y)^2 + 12.917m_1^3 - 0.972, \quad (4)$$

which applies to giants with $0.45 \leq (b - y) \leq 1.10$, $0.08 \leq m_1 \leq 0.92$, $0.08 \leq c_1 \leq 0.59$ and $-2.6 \lesssim [\text{Fe}/\text{H}] \lesssim 0.5$ dex, with a standard deviation of 0.15 dex (Figure 7). Notice that we apply this calibration to all our giants (cf. Figure 17), while for dwarfs we rely on the similar calibration derived in Casagrande et al. (2011). As there are no calibration giants above $[\text{Fe}/\text{H}] \simeq 0.5$ dex in the sample, if a star has a metallicity higher than this value, or if its Strömgren indices fall outside of the applicability range determined above, we flag the measurement. This and the *uvby* photometric quality flag determined in Section 2.3 identify stars with the most reliable metallicities based on the Strömgren photometry. As a result, these flags help to diagnose cases where stars with slightly unusual colors might return unrealistic metallicities.

Equation 4 differs from the functional form often used for giants, in particular it includes a dependence on the c_1 index, which was not measured in many past works (the low flux in the u band of relatively faint giants being too time consuming to measure with photoelectric photometers). The standard deviation of our giant calibration is somewhat larger than for dwarfs ($\lesssim 0.1$ dex, Casagrande et al. 2011); this could partly originate from the fact that the calibration sample already carries some uncertainty in the adopted reddening values. As we see later, the typical reddening uncertainty is around $\sigma_{E(B-V)} = 0.02$, and this affects Strömgren metallicities by 0.09 dex on average. We thus take a conservative approach and quadratically sum this error to the above standard deviation, yielding a typical uncertainty of 0.17 dex for our metallicities. As the SAGA survey continues, we plan to improve and expand the above calibration with a larger and

more uniform sample of giants having spectroscopic metallicities and abundances. In addition, Strömgren indices are known to be sensitive to more than just $[\text{Fe}/\text{H}]$ in cool stars and we plan to investigate this effect as well (e.g., Yong et al. 2008; Casagrande et al. 2011; Carretta et al. 2011).

The open cluster NGC 6819 offers the possibility to check the consistency between the metallicity calibration derived here for giants, and that used for dwarfs in our previous analysis of the solar neighborhood (Casagrande et al. 2011), as well as for the few dwarfs present in this sample (cf. Figure 17). We identify dwarfs and giants in NGC 6819 by using the same procedure for both: we cross-match our Strömgren observations with the radial velocity catalogue of Hole et al. (2009), and retain only single-stars with cluster membership probability $> 80\%$ and within $\simeq 7$ arcmin from the centre of the cluster. Notice that with this procedure, some of the cluster giants are not the same used for our metallicity calibration, which had more secure seismic membership (Stello et al. 2011). The comparison in Figure 8 shows that metallicities of dwarfs and giants agree on average. However, two things should be noticed. Firstly, the dwarfs exhibit a larger scatter, which is partly due to the larger photometric errors at fainter magnitudes, and because the sensitivity of Strömgren indices to metallicity is reduced for warmer dwarfs than for giants. Secondly, the peak of the two metallicity distributions differs by some 0.08 dex, with the giants being more metal-poor. Such an offset is not surprising, given that there might be a difference in the effective temperatures underlying the spectroscopic measurements used to build the dwarf (Casagrande et al. 2011) and the giant (derived here) metallicity calibrations. In fact, spectroscopic $[\text{Fe}/\text{H}]$ in giants are often derived using different flavors of the Alonso et al. (1999) T_{eff} scale. This is about 100 K cooler than the one now preferred for dwarfs and giants (Casagrande et al. 2010, 2014). Since the metallicity calibration for dwarfs used spectroscopic metallicities based on a T_{eff} scale hotter than Alonso et al. (1999), the aforementioned 100 K difference in giants can easily account for the metallicity offset

found here. Obviously, this zero point difference can be corrected, and for convenience the last term in Equation 4 is already shifted by this amount (a later comparison done in Figure 16 confirms that with such a correction giants in the cluster have indeed solar metallicity).

One could argue that $[\text{Fe}/\text{H}]$ should be slightly *lower* in dwarfs than giants belonging to the same stellar population due to the settling of heavy elements in main-sequence stars (e.g., Korn et al. 2007). However, because of the uncertainties discussed above and the relatively young age of the cluster ($\simeq 2.5$ Gyr, e.g., Yang et al. 2013; Jeffries et al. 2013; Sandquist et al. 2013), we believe this effect to be well within the uncertainties of our photometric metallicities.

3.3. Reddening

Even though the Galactic stripe observed for this work avoids excessively high values of color excess, non-negligible reddening is still present and must be corrected for before we can use photometry to derive stellar parameters. We did a comparison between the color excess reported in the Kepler Input Catalog for over 13 million objects, and $E(B - V)$ derived at their same position in the sky from the Schlegel et al. (1998) map (Figure 1). This revealed that that extinction in the Kepler Input Catalog lacks fine structure. This is not surprising since reddening in the Kepler Input Catalog is estimated using a simple dust model which assumes a smooth exponential disk with a scale height of 150 pc and 1 mag of attenuation in V band per kpc in the plane. Thus, color excess from the Kepler Input Catalog is used only as a starting point in our iterative scheme (Section 3).

Because we derive distances for all our stars, we can use three-dimensional extinction models. We use two different ones; that of Drimmel et al. (2003) and Amôres & Lépine (2005). Drimmel’s map is based on a dust distribution model applied to three Galactic

density components and rescaled to recover the observed far-infrared emission as observed by the COBE satellite. The Amôres & Lépine (2005) map is based on the measured gas density distribution, and translated into extinction under the assumption that gas and dust are well mixed. This model is available for two configurations, one assuming that the Galaxy is axisymmetric and one taking into account the spiral structure of the Galaxy.

The scale of the geometrical components used in all these models of the Galaxy is poorly known, and therefore the spatial distribution of extinction is uncertain. In fact, all these models suggest that rescaling factors can be used, should these be needed to satisfy reddening constraints in particular lines-of-sight.

Once again the open cluster NGC 6819 offers an important calibration point. It is located at the base of our Galactic stripe (Figure 1) and its giants are in the same magnitude range of the other *Kepler* giants with detected oscillations (Figure 8), thus broadly representing the typical mean distance probed in our investigation (see also Figure 2). Its reddening is also well constrained: we adopt $E(B - V) = 0.14$ from Bragaglia et al. (2001), which falls within the $0.12 - 0.16$ range of values found using different methods (e.g., Rosvick & Vandenberg 1998; Jeffries et al. 2013). Using our Strömgren photometry we apply the empirical method described in Milone et al. (2012b) to derive a 14×14 arcmin map of differential reddening centred on the cluster, which shows spatial variations of order ± 0.02 mag. This is consistent with the result of Platais et al. (2013), and reassures us that even at the lowest latitudes of our sample, differential reddening –whilst present– is not a major concern for our analysis.

We thus rescale the Drimmel et al. (2003) and Amôres & Lépine (2005) models to have $E(B - V) = 0.14$ at the position and distance of NGC 6819 (2.4 kpc from isochrone fitting, Yang et al. 2013), and use these recalibrated maps to estimate reddening for all our stars. Incidentally we notice that after this rescaling, the axisymmetric and the spiral

model of Amôres & Lépine (2005) are virtually identical (always to better than 0.01 mag) over the Galactic coordinates and distances covered in this investigation. For consistency we perform our analysis using the three models, but in practice we will always refer to both Drimmel et al. (2003) or Amôres & Lépine (2005) with the implicit assumption that the two flavors of the latter have been compared and that no substantial difference is found in the parameters derived.

With respect to extinction models, 2MASS photometry offers an alternative and empirical way to gauge the reddening . To this end, we select from the 2MASS Point Source Catalog (Skrutskie et al. 2006) a region roughly centred at the same longitude of our Galactic stripe, i.e. $|l - 72.5^\circ| < \pm 2.5^\circ$, and retain only targets having good infrared photometric flags⁹ (i.e. quality “AAA” and blend “111”). Figure 9 shows the $J - K_S$ vs. K_S plane for sources at four different latitudes. At the highest latitudes, where reddening is lowest, three main features are obvious: 1) the bluemost overdensity, which mainly comprises main-sequence and turn-off stars, 2) the central one mostly made up of giants, and 3) the rightmost and fainter group of cool dwarfs. Moving to lower Galactic latitudes these features blur, and a prominent puff of stars appears at the redmost colors. Reddening is indeed the main factor in shaping these morphological changes across the panels, as both age and metallicity play a minor role in the near-infrared color-magnitude diagram. This is shown with isochrones in the top right panel of the same figure. The main position of the red giant population is always located at approximately the same color $J - K_S \simeq 0.6 - 0.7$ regardless of the age (1 and 10 Gyr) and metallicity ($[\text{Fe}/\text{H}] \simeq -1$ and ~ 0) of the underlying population. We note that the isochrones shown here span a range considerably larger than the mean variation measured in this part of the disk. Thus, we can turn this argument around, to derive the value of reddening at each Galactic latitude such that the

⁹http://www.ipac.caltech.edu/2mass/releases/allsky/doc/sec2_2a.html

red giant population is restored to the same $J - K_S$. This can be used to verify the adopted Galaxy model reddening maps.

From this 2MASS stripe, we sample Galactic latitudes between 7° and 20° at constant steps of either 0.5° or 1° (to check different resolution effects) and each time derive the corresponding $J - K_S$ vs. K_S diagram. We consider only stars having apparent magnitudes $6 < K_S < 11$. This choice is representative of the magnitudes, and hence distances, of the bulk of our *Kepler* giants, and it also minimizes contamination from dwarfs (the reddest overdensity of dwarfs in the left panels of Figure 9 starts at somewhat fainter magnitudes). We then sample the reddening space in the range $0 \leq E(B - V) \leq 0.4$ in steps of 0.01, each time dereddening the color-apparent magnitude diagram at the value of $E(B - V)$ considered. For the sake of our analysis each color-apparent magnitude diagram is reduced to a histogram of the relative number of stars as function of $J - K_S$ color. The purpose is to derive a reddening map whose values are differential with respect to a reference value. Here, the histogram at the highest latitude sampled is taken as reference, and hence its color magnitude diagram is uncorrected for reddening, even if it could have a non-zero value of $E(B - V)$. All histograms derived at lower latitudes and for different values of $E(B - V)$ are benchmarked against this. Then, at each latitude we find the value of $E(B - V)$ which best matches the reference histogram in the color range $0.5 \leq J - K_S \leq 1.5$. These last values are set somewhat arbitrarily, to avoid the inclusion of the age-sensitive turn-off population and to probe the population of red giants well enough. We verified that changing these limits within reasonable values ($\simeq \pm 0.1$ mag) does not severely affect our results. This differential approach can then be put on an absolute scale should the value of reddening be known in one of the fields: this is indeed the case at the location of the open cluster. All $E(B - V)$ solutions are thus shifted by the amount needed to pass through the reddening of NGC 6819 at $b = 8.5^\circ$. As already mentioned, we sample Galactic latitudes in steps of both 0.5° and 1° to check whether our results depend on the adopted binning: the agreement

is quite reassuring, always within a few hundredths of a magnitude, although values of $E(B - V)$ derived sampling each 0.5° appear to be more noisy. This is expected because of the lower number of stars when using smaller bins, especially towards the highest latitudes. From this scatter we estimate $\sigma_{E(B-V)} = 0.02$ on average for the population *as a whole*. The reddening maps built with such a procedure have a rather coarse resolution, but benefit from being empirical and completely independent from both Drimmel et al. (2003) and Amôres & Lépine (2005).

The overall level of agreement between different maps and our empirical method is quite comforting provided that NGC 6819 is used as anchor point, and gives us confidence that our parameters are not severely affected by reddening. Notice that all our stellar parameters are derived using both the Drimmel et al. (2003) and Amôres & Lépine (2005) maps, while the empirical method developed here does not contain any distance information on single stars. However, besides validating the adopted extinction maps, the empirical method allows us to estimate the average uncertainty in reddening, at the level of 0.02 mag, and thus to assess the robustness of the stellar parameters we derive in the presence of this uncertainty.

3.4. Global asteroseismic parameters and evolutionary phase classification

Stellar oscillations driven by surface convection, such as those observed in the Sun and red giants, are visible in the power spectrum of time series photometry as a series of Lorentzian-shaped peaks whose peak height is modulated in frequency by a Gaussian-like envelope (e.g., Chaplin & Miglio 2013). Two quantities can be readily extracted from this oscillation pattern: the average separation between peaks of the same angular degree and consecutive radial order, the large frequency separation $\Delta\nu$, and the frequency of maximum amplitude ν_{\max} (e.g., Ulrich 1986; Brown et al. 1991). These global asteroseismic

parameters have been determined for the full sample of giants that we consider here. A few dwarfs are also present in the sample, and their classification comes from Chaplin et al. (2014).

Provided that the time resolution and quality of the observations are good enough, additional information can be extracted from the power spectrum of red giants thanks to the presence of *mixed modes* (see e.g., Bedding 2011, for a review). These oscillations have an acoustic character in the outer layers while behaving like gravity waves in the deep interior of a star, providing unique information about the stellar core. Stars evolving along the red giant branch, burning hydrogen in a shell around the inert helium core, are very difficult to distinguish from their helium core burning red clump counterparts by classical photometric and spectroscopic observations. However, RGB stars have a radiative core, while clump giants have a convective one. Measurement of the average spacing between mixed dipole modes, clearly separates these stars into two distinct populations of giants (Bedding et al. 2011; Mosser et al. 2012).

We have analyzed *Kepler* long-cadence data (Jenkins et al. 2010) through Quarter 15 for all giants in our sample. About 30% of the sample has been observed continuously throughout the mission (with a maximum dataset length of 1,350 days), while 70% have more than 10 quarters of data available. Simple-aperture photometry (SAP) data was used for our analysis. Instrumental flux discontinuities were corrected by fitting linear functions to 5-10 day subsets before and after each discontinuity (see, e.g., García et al. 2011). Finally, for all time series a quadratic Savitzky-Golay filter (Savitzky & Golay 1964) was applied to remove additional variability due to stellar activity and instrumental effects. Due to the wide range of oscillation periods covered in our sample we used two different filters: for stars with oscillation periods > 1 day we applied a 50 day filter, and for all remaining stars a 10 day filter was used.

We have classified the red giant stars into two main groups: those burning only hydrogen in a shell located on the RGB and those burning helium in the core in the red clump (RC). To distinguish these two groups we looked for the seismic signature of the stellar core properties according to Bedding et al. (2011). Specifically, we measured the period spacing of the dipole modes following the approach by Stello et al. (2013). We were able to measure the period spacing and unambiguously classify 427 stars in this way (169 RGB and 258 RC). The remaining giant stars did not show sufficient signal-to-noise in the frequency power spectra to provide reliable classification.

To extract the global oscillation parameters $\Delta\nu$ and ν_{\max} we have used the analysis pipeline described by Huber et al. (2009), which has been shown to agree well with other methods (Hekker et al. 2011a; Verner et al. 2011). Uncertainties for each parameter were determined through Monte-Carlo simulations, as described in Huber et al. (2011). For each value we added in quadrature an uncertainty arising from the use of solar reference values to estimate stellar properties (Section 3.5). The final median uncertainties on $\Delta\nu$ and ν_{\max} were 0.7% and 1.7%, reflecting the exquisite signal-to-noise of the *Kepler* data.

3.5. Masses, radii and distances

We have used grids of isochrones in combination with a Bayesian analysis that includes asteroseismic quantities to determine the stellar parameters of our sample. The reference isochrones are constructed from the non-canonical BaSTI models, which include core overshooting during the H-core burning phase and do not consider mass-loss. These isochrones have been computed explicitly for this work, while the BaSTI grid publically available¹⁰ assumes a Reimers (1975) mass-loss parameter of either $\eta = 0.4$ or $\eta = 0.2$.

¹⁰www.oa-teramo.inaf.it/BASTI

The helium to metal enrichment ratio is fixed at $\Delta Y/\Delta Z = 1.45$, consistent with the value inferred from the broadening of the low main-sequence (Casagrande et al. 2007) and from models of stellar nucleosynthesis and chemical evolution of the Galactic disk (e.g. Maeder 1992; Carigi & Peimbert 2008). A detailed account of the input physics of the models is given in Pietrinferni et al. (2004). We note that measurements of period spacings between mixed modes in clump stars observed by *Kepler* (Mosser et al. 2012) can only be reproduced if mixing beyond the formal Schwarzschild boundary of the He-burning convective core is included (Montalbán et al. 2013). In BaSTI models, this extra mixing is accounted for by including semiconvection during the He-core burning phase.

The Bayesian analysis is performed as described in Serenelli et al. (2013). In summary, if \mathbf{v} is a set of stellar parameters from models (e.g. mass, radius, metallicity, age, effective temperature), and \mathcal{O} the observed data, i.e. $\mathcal{O} \equiv (T_{\text{eff}}, \Delta\nu, \nu_{\text{max}}, [\text{Fe}/\text{H}])$, then according to Bayes’ rule the probability density function (PDF) of \mathbf{v} given \mathcal{O} , i.e. the posterior PDF $p(\mathbf{v}|\mathcal{O})$, is given by

$$p(\mathbf{v}|\mathcal{O}) \propto p(\mathbf{v}) p(\mathcal{O}|\mathbf{v}), \quad (5)$$

where $p(\mathcal{O}|\mathbf{v})$ is the likelihood of \mathcal{O} given \mathbf{v} , and $p(\mathbf{v})$ is the prior PDF of \mathbf{v} and represents prior knowledge on these quantities. The likelihood is computed assuming errors in \mathcal{O} follow Gaussian distributions.

For determining $p(\mathbf{v})$ we considered the following. The effective selection function of pulsating stars observed by *Kepler* is non trivial. Therefore, we cannot characterize a prior probability of stellar properties based on the fact that the star is in the *Kepler* field. For this reason, we assume a flat prior in $[\text{Fe}/\text{H}]$ and age including only a strict cut on the latter at 16 Gyr. For the prior in mass we assume a standard Salpeter IMF. In the cases where it is possible to measure the separation between mixed modes (see Section 3.4 above), the information obtained on the evolutionary phase of the star is also included as a (binary)

prior such that only stellar models corresponding to the determined evolutionary phase are used in the analysis. When this information is not available all models are considered and stellar properties can suffer from large uncertainties due to both the RGB and clump evolutionary phases having non-negligible likelihoods. Bimodal probability distributions could in principle arise in those cases, influencing the estimation of reliable properties for these stars.

Once the posterior PDF has been computed for a star, the posterior PDF of any stellar quantity x can be simply obtained as

$$p(x|\mathcal{O}) = \int \delta(x(\mathbf{v}) - x) p(\mathbf{v}|\mathcal{O}) w_v d^3v, \quad (6)$$

where w_v accounts for the volume of parameter space occupied by an isochrone point characterized by \mathbf{v} (see appendix A in Casagrande et al. 2011).

The computation of the likelihood function in Equation 5 requires determination of theoretical values for $\Delta\nu$ and ν_{\max} . Those can be derived from the adopted grid of isochrones thanks to scaling relations. To a good approximation, $\Delta\nu$ scales with the mean density of the star (Ulrich 1986), while ν_{\max} is related to the surface properties (Brown et al. 1991; Kjeldsen & Bedding 1995). From the solar values, two asteroseismic scaling relations can be written (e.g., Stello et al. 2009; Miglio et al. 2009):

$$\frac{\Delta\nu}{\Delta\nu_{\odot}} \simeq \frac{(M/M_{\odot})^{0.5} (T_{\text{eff}}/T_{\text{eff},\odot})^3}{(L/L_{\odot})^{0.75}}, \quad (7)$$

$$\frac{\nu_{\max}}{\nu_{\max,\odot}} \simeq \frac{M/M_{\odot} (T_{\text{eff}}/T_{\text{eff},\odot})^{3.5}}{L/L_{\odot}}, \quad (8)$$

where $\Delta\nu_{\odot} = 135.1 \mu\text{Hz}$ and $\nu_{\max,\odot} = 3090 \mu\text{Hz}$ are the values observed in the Sun for the adopted method in this paper (Huber et al. 2011). Using parallaxes and interferometric measurements, radii determined using these scaling relations have been shown to be accurate to better than 5% in dwarfs (e.g., Silva Aguirre et al. 2012; Huber et al. 2012;

White et al. 2013). Further tests on the reliability of the scaling relations are summarized in Miglio et al. (2013a).

Having now all the information needed to compute both the prior and the likelihood, the PDF for the relevant parameters of each star can be computed, including masses and radii. Further, precise distances can also be determined by scaling these radii with the angular diameters obtained via the IRFM. As summarized in Section 3, stellar parameters have been determined via an iterative process coupling the photometric and asteroseismic parameters. In every iteration we used the median and 68% confidence levels of the PDF to determine the central value and (asymmetric) uncertainty of each quantity. We call these errors “formal uncertainties”, and we explore the effect of using different stellar models and pipelines on the error budget later in Section 3.7.

3.6. Unresolved binary contamination

In principle, the presence of undetected binaries is important since, should this happen, the colors measured for a star would also carry the contribution from its companion, thus affecting all photometric quantities derived and subsequently used for the seismic analysis (Sections 3.1 - 3.5). Fortunately our sample comprises mostly RGB stars, for which the fraction of similar luminosity binaries is extremely rare ($\sim 1\%$, e.g., Nataf et al. 2012). Moving to lower mass companions, the fraction of spectroscopic binaries among K and M giants ranges from ~ 6 to $\sim 30\%$, where observational difficulties as well as accounting for selection effects prevent better estimates (e.g., Frankowski et al. 2009).

A number of important photometric flags are available for all seismic stars used in this work, 96% of our targets having the best possible 2MASS pedigree⁹: quality flag “AAA”, blend flag “111” (meaning one component is fit to the source) and contamination and

confusion flag “000” (meaning the source is unaffected by known artifacts) in all three infrared bands. The remaining 4% of stars with one or more flags set differently from above, usually have larger photometric errors which thus are accounted for in our Monte-Carlo, naturally resulting in larger error bars (see Section 3.7).

Synthetic photometry offers a qualitative way of assessing the level of contamination expected from a companion. From the MARCS library of synthetic spectra (Gustafsson et al. 2008) we assume $\log g = 2.5$, $[\text{Fe}/\text{H}] = 0$ and $T_{\text{eff}} = 4750$ K for a typical giant to which we assign a radius of $10 R_{\odot}$. For the secondary, we consider two representative cases: in one the companion is identical to the Sun, while in the other it is an M dwarf ($\log g = 5.0$, $[\text{Fe}/\text{H}] = 0$ and $T_{\text{eff}} = 4000$) with radius $0.7 R_{\odot}$. Assuming that both binary components randomly sample the initial mass function, this last case is likely to be the most probable, given that by number M dwarfs are the dominant stellar population in the Galaxy (e.g., Reid & Hawley 2005).

As expected, the flux contribution of an M dwarf is entirely negligible compared to a giant: optical and infrared colors are affected by 1 to 4 millimag, thus having no impact on the IRFM. Strömgren $b - y$, m_1 and c_1 indices are even less affected, a few parts over ten thousand at most. In the presence of a solar companion, the effect is between 0.01 and 0.02 magnitudes in both broad-band and Strömgren colors, with only moderate impact on the photometric parameters derived. Our conservative error bars account for any such uncertainty. Of course, other combinations in the ratio of the primary to secondary effective temperature and radius are possible, but the two cases explored above are representative of the most common scenarios, and give us confidence that binary contamination, when present, barely affects our parameters.

Kepler data provides an additional tool to quantify binary contamination in the sample. In addition to $\Delta\nu$ and ν_{max} the asteroseismic analysis described in Section 3.4

yielded estimates of the global oscillation amplitude, which is well-known to correlate with stellar properties (see, e.g., Corsaro et al. 2013). Any near equal-mass binary companion would result in a second oscillation signal with nearly equal frequency, causing a significant dilution of the observed amplitude. A second oscillation signal is observed for only five stars in our sample, with estimated luminosity ratios ranging from $\simeq 0.4 - 0.8$. These stars have been flagged in the analysis.

3.7. Total error budget

For all 9 possible different combinations of broad-band photometric systems (three) and reddening maps (three), we derive both self-consistent parameters and uncertainties. For each star, uncertainties in the physical parameters derived from the IRFM (effective temperature, bolometric flux and angular diameter) are computed in a fashion very similar to Casagrande et al. (2010). First, a Monte-Carlo is run to account for random photometric errors, according to the set of filters used in the IRFM. We use uncertainties quoted for each band in 2MASS (JHK_S) and APASS (BV and $g'r'i'$); no star-by-star uncertainties are reported in the KIC ($griz$), and we thus use a constant uncertainty of 0.02 mag in each filter (figure 4 in Brown et al. 2011).

For reddening we explore a systematic variation of $E(B - V) = \pm 0.02$ with respect to the values adopted from each map. This variation in reddening is also used to compute by how much the Strömgren metallicities change. As already mentioned (Section 3.2), this metallicity variation is added quadratically to the scatter of the $[\text{Fe}/\text{H}]$ calibration, returning a typical global uncertainty of 0.17 dex. This is used to compute how much the parameters derived via the IRFM vary, although we recall once again that the IRFM is only mildly sensitive to the input $[\text{Fe}/\text{H}]$. In this way, reddening enters our errors twice, both in the broad-band colors and in the metallicities used in the IRFM; the choice to

maximize its effect is motivated by the fact that we aim to derive realistic and conservative uncertainties. Finally the effect of varying $\log g$ by 0.1 dex is included: the precision of seismic gravities is actually much higher ($\lesssim 0.03$ dex, e.g., Gai et al. 2011; Thygesen et al. 2012; Morel & Miglio 2012) but the IRFM is so largely insensitive to $\log g$ that even this very conservative uncertainty has virtually no effect on the error budget. All uncertainties listed above (Monte-Carlo, reddening, metallicity and gravity) are added quadratically, and further increased by 1.0% and 0.7% for bolometric fluxes and angular diameters and 20 K for T_{eff} to account for our uncertainty in the absolute zero-point of those scales (Casagrande et al. 2010). We recall that the effective temperature, bolometric flux and angular diameter of each star are usually derived using three different implementations of the IRFM ($grizJHK_S$, $BVJHK_S$ and $g'r'i'JHK_S$): comparison among those is shown in Figure 10. For the sake of the latter, the same reddening map is used although in some cases distances change depending on the filter combination used in the IRFM, and thus the values derived for $E(B - V)$ change as well, even when using the same map. Metallicities are derived from Strömgren colors only, although for the reason just explained $E(B - V)$ might be slightly different among the three implementations of the IRFM. Fortunately this reddening variation *within* the same map has virtually no effect on $[\text{Fe}/\text{H}]$, often being null and typically well below 0.01 dex.

Having now three different sets of \mathcal{F}_{Bol} , θ , T_{eff} and $[\text{Fe}/\text{H}]$ each with its own error, we can combine this information by using the weighted average. The values derived in this way for a given reddening map are dubbed “consolidated” parameters. In the ideal case, different filter combinations should all return the same values for a given reddening map. Within the uncertainties, this is indeed the case (Figure 10). The weighted sample standard deviation, which measures the overdispersion of the weighted averaged parameters, tells us their internal consistency: reassuringly, this is very close to the values obtained with the Monte-Carlo for each implementation of the IRFM. To obtain the final global errors, we

quadratically add the weighted sample standard deviation to the errors computed above for each star. Their median values are 82 K in T_{eff} , 0.17 dex in $[\text{Fe}/\text{H}]$, 2% in angular diameters and 5% in bolometric fluxes.

The procedure outlined above is repeated for each reddening map. Comparison between the results obtained adopting Drimmel et al. (2003) or Amôres & Lépine (2005) is shown in Figure 11: as expected from our conservative approach in estimating realistic error bars, results always agree within the uncertainties. Median differences are relatively small and rather uniform with no particular dependence on Galactic coordinates, especially for latitudes above 10° . At smaller b the agreement is much better and reflects our use of the reddening of NGC 6819 as an anchor point.

These consolidated parameters are used once again into the seismic scheme described in Section 3.5 to derive a final set of radii, distances and masses with median formal uncertainties of order 2%, 3%, and 5% respectively. These values are of the same order as those found in other asteroseismic studies when reliable information on stellar effective temperatures and metallicities are available. In particular, errors in masses and radii are positively correlated, and this leads to very small errors in gravities (e.g. Gai et al. 2011; Creevey et al. 2013; Chaplin et al. 2014). Nevertheless, it should be kept in mind that as of yet, there are only few empirical tests of the accuracy of the scaling relations when applied to giants (see also discussion in Section 3.5), and modest systematic errors are thus possible (Miglio et al. 2012). However, the clear separation of the first and secondary clump in our data gives confidence on the internal precision of our gravities. Figure 12 extends the comparison between different reddening maps to seismic quantities, where stars with different seismic classification are highlighted in colors; differences are always within the error bars also in this case. We also explore the impact in the derived stellar parameters of varying the input physics in our reference BaSTI grid of isochrones. We test the effect

of switching on mass-loss with high efficiency ($\eta = 0.4$) during the evolution, finding that the formal uncertainties quoted above are more than two times larger than the median difference in the derived stellar parameters. Similarly, isochrones with no core overshoot during the main-sequence phase give differences about ten times smaller than the formal uncertainties. Hence, these effects have overall little impact on the parameters derived here (although this would not always be the case for stellar ages).

To account for systematics arising from different evolutionary codes and implementation of input physics we derived Bayesian stellar parameters using an extension of the grid of models presented in Serenelli et al. (2013), constructed using the GARching STellar Evolution Code (GARSTEC, Weiss & Schlattl 2008) and covering a mass and metallicity range of $0.6 \leq M_{\odot} \leq 3.0$ and $-3.0 \leq [\text{Fe}/\text{H}] \leq +0.5$. Similarly, we determined stellar properties from BaSTI evolutionary tracks using the Monte-Carlo approach described in Huber et al. (2013), to explore systematics introduced by our Bayesian pipeline. Comparison between our reference parameters and those derived with a different approach are shown in Figure 13. For stars with known seismic classification differences are usually only a few percent, while they can grow considerably larger for stars without seismic classification.

For the final and global uncertainties in $\log g$ (and densities), radii, distances and masses, we add quadratically to the formal uncertainties from our BaSTI reference models half the difference between those results and the ones obtained with the GARSTEC grid and the Monte-Carlo approach. Their median values are 82 K in T_{eff} , 0.17 dex in $[\text{Fe}/\text{H}]$, 0.006 dex in $\log g$, 1.5% in stellar density, 2.4% in radius, 3.3% in distance and 6.0% in mass. As expected, the uncertainty in asteroseismic quantities is also smaller for stars with known evolutionary phase classification compared to stars for which this information is unknown (Figure 14). In all instances, it should be kept in mind that while we have carefully

accounted for various sources of uncertainties, the accuracy of the seismic parameters is currently limited by empirical tests of the scaling relations, which here are assumed to be exact.

3.8. Adopted parameters

As already described, stellar parameters have been derived self-consistently for 9 different combinations of photometric systems and reddening maps. We also verified in the previous Section that the use of three different photometric systems in the IRFM did not introduce any major difference in the results and hence merged those, thus curbing our combinations to the three reddening maps. For our field, the symmetric and spiral model of Amôres & Lépine (2005) yield virtually identical results (Section 3.3), effectively meaning that we are dealing with 2 different sets of results.

Figure 15 compares the model (\mathbf{v} in Equation 5) and empirical effective temperatures (from the IRFM) derived with the two reddening maps. Notice that the effective temperature is only one of many parameters entering our Bayesian scheme, and in fact the model effective temperature barely changes when adopting a different reddening map (see top left panel in Figure 12, where the mean and median difference is only 12 and 2 K, respectively). While differences might exist between the empirical and the model T_{eff} scale, the ΔT_{eff} trend with respect to Galactic latitude in the Drimmel et al. (2003) case (Figure 15, right panel) reminds that of Figure 9 (lower right panel), thus dictating our preference for Amôres & Lépine (2005). Notice though, our reddening errors account for the difference between the two maps (Section 3.7).

To summarize, our photometric stellar parameters are derived adopting the Amôres & Lépine (2005) reddening map (rescaled to match the reddening of NGC 6819)

with seismic parameters obtained using the BaSTI non-canonical isochrones with no mass-loss and the global errors derived in Section 3.7 and shown in Figure 14. The catalogue is available in the electronic version of the journal, and Table 1 provides information about each tabular column. Depending on the purpose for which we use our parameters, we can also restrict our analysis to include only stars with more certain seismic classification.

3.9. External validation of derived parameters

Throughout the paper we have used the open cluster NGC 6819 as a benchmark point. Here we used it to further check the consistency of the main parameters derived from the seismic analysis. Figure 16 shows the metallicity distribution of the seismic giants in the cluster: just as expected from the discussion of Section 3.2 the solar metallicity of this cluster is reproduced. More interesting is the second panel, which shows the distance distribution for the same stars. Their distance sharply peaks at a value of 2.38 ± 0.08 kpc, in excellent agreement with similar estimates obtained from isochrone fitting (e.g., Yang et al. 2013; Sandquist et al. 2013).

Figure 17 shows all seismic targets analyzed in this work in the empirical (IRFM) T_{eff} – seismic $\log g$ plane: the very clear presence of primary and secondary clump stars appear. The latter population was discovered by Girardi et al. (1998) using *Hipparcos* parallaxes and its detection here clearly illustrates the precision we have achieved. Such a population is composed by stars with $M \gtrsim 1.8 M_{\odot}$ that ignite helium in non-degenerate conditions and it is relatively short-lived, peaking at ~ 1 Gyr (e.g., Girardi 1999, where the exact mass and age depend on the adopted models).

4. Comparison with other works

4.1. KIC

Currently, the largest database of stellar parameters for stars in the *Kepler* field is provided by the Kepler Input Catalogue (Brown et al. 2011) which was originally conceived as a tool to optimize the target selection (Batalha et al. 2010), and thus provide only approximate estimates of stellar parameters. A number of investigations has highlighted inaccuracies in its parameters (e.g., Molenda-Żakowicz et al. 2011; Pinsonneault et al. 2012; Thygesen et al. 2012).

In Figure 18 we compare the SAGA T_{eff} and $[\text{Fe}/\text{H}]$ against the KIC. The effective temperatures of giants are in overall reasonable agreement (KIC being some 20 K hotter but with a large 80 K scatter), also considering uncertainties related to reddening. However, a clear offset appears when moving to main-sequence stars, spurring systematic differences by more than 200 K (SAGA being hotter). These trends are in agreement with similar findings for dwarfs by Pinsonneault et al. (2012) and for giants by Thygesen et al. (2012).

Concerning $[\text{Fe}/\text{H}]$, the KIC performs less well. For giants $\Delta[\text{Fe}/\text{H}] = -0.13$ dex (SAGA minus KIC) and $\sigma = 0.35$ dex, which improves only moderately if restricting to stars with the most reliable Strömgren metallicities. Part of the scatter might arise from the fact that metallicities in the KIC are more representative of the overall metal content $[\text{M}/\text{H}]$, while we calibrated our photometry using direct $[\text{Fe}/\text{H}]$ measurements. Field stars in the Galactic disk are known to generally increase their $[\alpha/\text{Fe}]$ content going towards lower metallicities (e.g., Tinsley 1979; McWilliam 1997; Matteucci 2001; Pagel 2009). If we assign $[\alpha/\text{Fe}]$ to our stars according to the analytic model of Pagel & Tautvaisiene (1995) and compute their $[\text{M}/\text{H}]$, the offset and the scatter reduce to -0.07 dex and 0.31 dex, respectively, with a particular improvement for stars with metallicities below -1 dex. A

similar trend towards low metallicities in the KIC can also be seen in the comparison of Dong et al. (2013).

It is also interesting to compare our results with the reddening and surface gravities reported in the KIC. Confidence in the SAGA values of $E(B - V)$ comes from the fact that the good agreement of our photometric T_{eff} with respect to spectroscopy (next Section) disappears if the reddening of the KIC is adopted. Our calibrated reddening map indicates that the color excess reported in the KIC is increasingly overestimated for increasing values of $E(B - V)$. The correlation shown in Figure 19a also appears when the same quantity on the y -axis is plotted as function of apparent magnitudes or distances (which in turn are highly correlated); thus indicating that fainter and further away objects in the KIC are more likely to have inaccurate values of reddening. This suggests that the scale height and/or the attenuation adopted in the KIC dust model are the primary causes for this disagreement. Another spatial dependence appears when plotting the percent difference as function of Galactic latitude b (Figure 19b). At higher b reddening decreases, but percentage-wise the KIC overestimation is larger. A linear fit of the trend in Figure 19a accounts for most of the difference between the KIC and SAGA, but it does not remove the trend of the fractional error as function of b . This is accounted for by fitting the ratio between the color excess in SAGA and the values obtained from the linear fit above. The corrected reddening we derive for the color excess in the KIC is thus:

$$E(B - V) = [0.55 E(B - V)_{\text{KIC}} + 0.008](1.2 - 0.02 b), \quad (9)$$

where the first term is dominant, while the second accounts for the spatial dependency of the fractional difference. Since all reddening values in the KIC are derived using the same dust model, the correction proposed here likely applies for most of the stars in the *Kepler* field. It should be kept in mind that Equation 9 is tailored to the stripe analyzed in this work.

Figure 19c compares the surface gravities we derived from asteroseismology with the values reported in the KIC. The sharp cut at $\log g \sim 3.4$ reflects the KIC-based pre-selection of giants for measuring oscillations (Ciardi et al. 2011; Hekker et al. 2011b). We have already discussed in Section 3.7 the precision of asteroseismic gravities; $\log g$ values in the KIC were derived with the purpose of broadly distinguishing between dwarfs and giant, and we confirm here the overall success in doing this (but see Huber et al. 2014, for a more detailed discussion).

4.2. APOGEE

The APO Galactic Evolution Experiment (APOGEE) uses high-resolution H -band spectra to observe some 10^5 giants across the Galaxy (Ahn et al. 2013). As part of this project, a number of targets in the *Kepler* field has been observed and are now publicly available via DR10. Here we compare our SAGA parameters with the spectroscopic ones from APOGEE. Details on the derivation of those can be found in Mészáros et al. (2013). Briefly, two sets of parameters are provided: raw and corrected T_{eff} and $[\text{Fe}/\text{H}]$. Corrections for the latter are determined from fitting polynomials to reproduce a number of benchmark stars and clusters, and amount up to 0.2 dex in metallicity and 100 K in T_{eff} for the stars used here. The comparison carried out here is with respect to the corrected APOGEE parameters.

The agreement in T_{eff} is good overall with $\Delta T_{\text{eff}} = 90 \pm 105$ K, SAGA being hotter. It is particularly good below $\simeq 4600$ K ($\Delta T_{\text{eff}} = 0 \pm 34$ K) although APOGEE tends to increasingly underestimate T_{eff} descending the RGB towards hotter stars. Concerning metallicities, the comparison looks tighter because of the much higher quality of the APOGEE parameters with respect to the KIC. The same trend already highlighted in Figure 18 appears, although it is not as dramatic when we restrict the sample to stars

with the best Strömgren photometry, $\Delta[\text{Fe}/\text{H}] = -0.11 \pm 0.26$ dex (only slightly larger than expected considering uncertainties in the SAGA and APOGEE values). While the raw APOGEE metallicities are more representative of the global $[\text{M}/\text{H}]$, their corrected ones are forced to reproduce $[\text{Fe}/\text{H}]$ of a number of benchmark clusters (see discussion in Mészáros et al. 2013). A few of these clusters are also used for our metallicity calibration: using for them the same $[\text{Fe}/\text{H}]$ adopted by APOGEE changes our metallicities at the level of 0.1 dex toward the metal-poor regime.

5. Conclusions

In this paper we have presented Strömgren photometry of a stripe in the *Kepler* field. While the ultimate purpose is to use these observations to provide homogeneous and reliable stellar parameters for both candidate planet host and seismic stars, the geometry chosen for our observations already enables Galactic studies using stars with detected oscillations.

The strength of our approach is in the coupling of classical and asteroseismic parameters: effective temperatures (from the InfraRed Flux Method), metallicities (from Strömgren indices), masses, and radii (from seismology) are derived iteratively and self-consistently, thus giving access to other quantities such as reddening and distances, and providing a complete picture of the seismic population in our observed Galactic fields.

The open cluster NGC 6819 is located at the base of the observed stripe and offers an important benchmark to verify the soundness of our results. In particular, it allows us to anchor the metallicity scale of giants on the same zero-point used for investigating properties in the solar neighborhood via dwarfs and subgiants from the Geneva-Copenhagen Survey (Casagrande et al. 2011). This is crucial if for example we wish to use nearby stars and/or giants (up to $\simeq 6$ kpc across the Galactic disk in this work) for the purpose of

understanding the formation and evolution of stellar populations in the Milky Way.

The sample presented here covers latitudes between 8 and 20 degrees above the Galactic plane. The stellar parameters derived here are already well suited for a number of investigations; in particular the seismic classification allows us to distinguish between stars ascending the red giants branch burning hydrogen in a shell, and those which have also ignited helium burning in their core. Concerning the latter, the precision achieved allows us to discern between primary and secondary clump, hence whether the core ignites degenerately or not. With this information, and the parameters so far derived, we are thus in the position of using these stars to compute reliable stellar ages and investigate, for example the age-metallicity relation and the age/metallicity gradients across this part of the Galactic disk. Further, calibrating photometric metallicities and age dating techniques on the present sample, a deep all-sky Strömgren survey promises a leading role for Galactic studies.

We thank the referee for a prompt and constructive report. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. This paper makes use of data from the AAVSO Photometric All Sky Survey, whose funding has been provided by the Robert Martin Ayers Sciences Fund. Funding for the Stellar Astrophysics Centre is provided by The Danish National Research Foundation (Grant agreement No. DNR106). The research is supported by the ASTERISK project (ASTERoseismic Investigations with SONG and *Kepler*) funded by the European Research Council (Grant agreement No. 267864). D.H. is supported by an appointment to the NASA Postdoctoral Program at Ames Research Center, administered by Oak Ridge Associated Universities through a contract with NASA. A.M.S. is partially

supported by the MICINN grant AYA2011-24704. This work has been supported by an Australian Research Council Laureate Fellowship to MA (grant FL110100012).

REFERENCES

- Aden, D. 2011, Ph.D. thesis, Department of Astronomy and Theoretical Physics, Lund University
- Adén, D., et al. 2009, *A&A*, 506, 1147
- Adibekyan, V. Z., et al. 2013, *A&A*, 554, A44
- Ahn, C. P., et al. 2013, ArXiv e-prints
- Alonso, A., Arribas, S., & Martinez-Roger, C. 1996, *A&AS*, 117, 227
- Alonso, A., Arribas, S., & Martínez-Roger, C. 1999, *A&AS*, 140, 261
- Amôres, E. B., & Lépine, J. R. D. 2005, *AJ*, 130, 659
- Árnadóttir, A. S., Feltzing, S., & Lundström, I. 2010, *A&A*, 521, A40
- Baglin, A., & Fridlund, M. 2006, in *ESA Special Publication*, Vol. 1306, *ESA Special Publication*, ed. M. Fridlund, A. Baglin, J. Lochard, & L. Conroy, 11
- Batalha, N. M., et al. 2010, *ApJ*, 713, L109
- Batalha, N. M., et al. 2013, *The Astrophysical Journal Supplement Series*, 204, 24
- Bedding, T. R. 2011, in *Asteroseismology*, *Canary Islands Winter School of Astrophysics*, Vol XXII, ed P L Palle (Cambridge: Cambridge Univ Press), (arXiv:11071723)
- Bedding, T. R., et al. 2011, *Nature*, 471, 608
- Bensby, T., Feltzing, S., & Oey, M. S. 2013, ArXiv e-prints
- Bessell, M. S. 2005, *ARA&A*, 43, 293

- Bird, J. C., Kazantzidis, S., Weinberg, D. H., Guedes, J., Callegari, S., Mayer, L., & Madau, P. 2013, *ApJ*, 773, 43
- Bragaglia, A., et al. 2001, *AJ*, 121, 327
- Brown, T. M., Gilliland, R. L., Noyes, R. W., & Ramsey, L. W. 1991, *ApJ*, 368, 599
- Brown, T. M., Latham, D. W., Everett, M. E., & Esquerdo, G. A. 2011, *AJ*, 142, 112
- Calamida, A., et al. 2007, *ApJ*, 670, 400
- Carigi, L., & Peimbert, M. 2008, *Rev. Mexicana Astron. Astrofis.*, 44, 341
- Carretta, E., Bragaglia, A., Gratton, R., D’Orazi D’Orazi, V., & Lucatello, S. 2011, *A&A*, 535, A121
- Carretta, E., et al. 2009, *A&A*, 505, 117
- Casagrande, L., Flynn, C., Portinari, L., Girardi, L., & Jimenez, R. 2007, *MNRAS*, 382, 1516
- Casagrande, L., Portinari, L., & Flynn, C. 2006, *MNRAS*, 373, 13
- Casagrande, L., et al. 2014, *ArXiv:1401.3754*
- Casagrande, L., Ramírez, I., Meléndez, J., & Asplund, M. 2012, *ApJ*, 761, 16
- Casagrande, L., Ramírez, I., Meléndez, J., Bessell, M., & Asplund, M. 2010, *A&A*, 512, A54
- Casagrande, L., Schönrich, R., Asplund, M., Cassisi, S., Ramírez, I., Meléndez, J., Bensby, T., & Feltzing, S. 2011, *A&A*, 530, A138
- Casagrande, L., & VandenBerg, D. 2014, *MNRAS*, to be submitted
- Cescutti, G., Matteucci, F., François, P., & Chiappini, C. 2007, *A&A*, 462, 943

- Chaplin, W. J., et al. 2014, *ApJS*, 210, 1
- Chaplin, W. J., et al. 2011, *Science*, 332, 213
- Chaplin, W. J., & Miglio, A. 2013, *ArXiv e-prints*
- Ciardi, D. R., et al. 2011, *AJ*, 141, 108
- Cohen, J. G. 2011, *ApJ*, 740, L38
- Corsaro, E., Fröhlich, H.-E., Bonanno, A., Huber, D., Bedding, T. R., Benomar, O., De Ridder, J., & Stello, D. 2013, *MNRAS*, 430, 2313
- Crawford, D. L. 1975, *AJ*, 80, 955
- Creevey, O. L., et al. 2013, *MNRAS*, 431, 2419
- De Ridder, J., et al. 2009, *Nature*, 459, 398
- Dong, S., Zheng, Z., & Zhu, Z. 2013, *ArXiv e-prints*
- Drew, J. E., et al. 2005, *MNRAS*, 362, 753
- Drimmel, R., Cabrera-Lavers, A., & López-Corredoira, M. 2003, *A&A*, 409, 205
- Eggen, O. J., Lynden-Bell, D., & Sandage, A. R. 1962, *ApJ*, 136, 748
- Faria, D., Feltzing, S., Lundström, I., Gilmore, G., Wahlgren, G. M., Ardeberg, A., & Linde, P. 2007, *A&A*, 465, 357
- Farmer, R., Kolb, U., & Norton, A. J. 2013, *MNRAS*, 433, 1133
- Feltzing, S., & Bensby, T. 2008, *Physica Scripta Volume T*, 133, 014031
- Frankowski, A., Famaey, B., van Eck, S., Mayor, M., Udry, S., & Jorissen, A. 2009, *A&A*, 498, 479

- Freeman, K. 2013, PASA, in press
- Gai, N., Basu, S., Chaplin, W. J., & Elsworth, Y. 2011, ApJ, 730, 63
- García, R. A., et al. 2011, MNRAS, 414, L6
- Gilliland, R. L., et al. 2010, PASP, 122, 131
- Gilmore, G., et al. 2012, The Messenger, 147, 25
- Girardi, L. 1999, MNRAS, 308, 818
- Girardi, L., Groenewegen, M. A. T., Weiss, A., & Salaris, M. 1998, MNRAS, 301, 149
- Gliese, W. 1957, Astron. Rechen-Institut, Heidelberg, 89 Seiten, 8, 1
- Grebel, E. K., & Richtler, T. 1992, A&A, 253, 359
- Greiss, S., et al. 2012, AJ, 144, 24
- Groot, P. J., et al. 2009, MNRAS, 399, 323
- Grundahl, F., Stetson, P. B., & Andersen, M. I. 2002, A&A, 395, 481
- Grundahl, F., Vandenberg, D. A., & Andersen, M. I. 1998, ApJ, 500, L179
- Grundahl, F., Vandenberg, D. A., Bell, R. A., Andersen, M. I., & Stetson, P. B. 2000, AJ, 120, 1884
- Gustafsson, B., Edvardsson, B., Eriksson, K., Jørgensen, U. G., Nordlund, Å., & Plez, B. 2008, A&A, 486, 951
- Harris, W. E. 1996, AJ, 112, 1487
- Harris, W. E., Fitzgerald, M. P., & Reed, B. C. 1981, PASP, 93, 507

- Haywood, M. 2002, MNRAS, 337, 151
- Hekker, S., et al. 2011a, A&A, 525, A131
- Hekker, S., et al. 2011b, MNRAS, 414, 2594
- Hilker, M. 2000, A&A, 355, 994
- Hole, K. T., Geller, A. M., Mathieu, R. D., Platais, I., Meibom, S., & Latham, D. W. 2009, AJ, 138, 159
- Huber, D., et al. 2011, ApJ, 743, 143
- Huber, D., et al. 2013, ApJ, 767, 127
- Huber, D., et al. 2012, ApJ, 760, 32
- Huber, D., et al. 2014, ApJS, 211, 2
- Huber, D., Stello, D., Bedding, T. R., Chaplin, W. J., Arentoft, T., Quirion, P.-O., & Kjeldsen, H. 2009, Communications in Asteroseismology, 160, 74
- Irwin, M., & Lewis, J. 2001, New A Rev., 45, 105
- Jeffries, M. W., Jr., et al. 2013, ArXiv e-prints
- Jenkins, J. M., et al. 2010, ApJ, 713, L120
- Jørgensen, B. R., & Lindegren, L. 2005, A&A, 436, 127
- Kjeldsen, H., & Bedding, T. R. 1995, A&A, 293, 87
- Kobayashi, C., & Nakasato, N. 2011, ApJ, 729, 16
- Korn, A. J., Grundahl, F., Richard, O., Mashonkina, L., Barklem, P. S., Collet, R., Gustafsson, B., & Piskunov, N. 2007, ApJ, 671, 402

- Lebreton, Y., & Montalbán, J. 2009, in IAU Symposium, Vol. 258, IAU Symposium, ed. E. E. Mamajek, D. R. Soderblom, & R. F. G. Wyse, 419
- Lind, K., Charbonnel, C., Decressin, T., Primas, F., Grundahl, F., & Asplund, M. 2011, *A&A*, 527, A148
- Lindegren, L., & Perryman, M. A. C. 1996, *A&AS*, 116, 579
- Liu, C., Bailer-Jones, C. A. L., Sordo, R., Vallenari, A., Borrachero, R., Luri, X., & Sartoretti, P. 2012, *MNRAS*, 426, 2463
- Maeder, A. 1992, *A&A*, 264, 105
- Massey, P., & Davis, L. E. 1992, A user’s guide to stellar CCD photometry with IRAF
- Matteucci, F., ed. 2001, *Astrophysics and Space Science Library*, Vol. 253, The chemical evolution of the Galaxy
- McWilliam, A. 1997, *ARA&A*, 35, 503
- Meléndez, J., Schuster, W. J., Silva, J. S., Ramírez, I., Casagrande, L., & Coelho, P. 2010, *A&A*, 522, A98
- Mészáros, S., et al. 2013, *AJ*, 146, 133
- Miglio, A., et al. 2012, *MNRAS*, 419, 2077
- Miglio, A., et al. 2013a, in *European Physical Journal Web of Conferences*, Vol. 43, *European Physical Journal Web of Conferences*, 3004
- Miglio, A., et al. 2013b, *MNRAS*, 429, 423
- Miglio, A., et al. 2009, *A&A*, 503, L21

- Milone, A. P., Marino, A. F., Piotto, G., Bedin, L. R., Anderson, J., Aparicio, A., Cassisi, S., & Rich, R. M. 2012a, *ApJ*, 745, 27
- Milone, A. P., et al. 2012b, *A&A*, 540, A16
- Minchev, I., Chiappini, C., & Martig, M. 2012, *ArXiv e-prints*
- Minniti, D., et al. 2010, *New A*, 15, 433
- Molenda-Żakowicz, J., Latham, D. W., Catanzaro, G., Frasca, A., & Quinn, S. N. 2011, *MNRAS*, 412, 1210
- Montalbán, J., Miglio, A., Noels, A., Dupret, M. A., Scuflaire, R., & Ventura, P. 2013, *The Astrophysical Journal*, 766, 118
- Morel, T., & Miglio, A. 2012, *MNRAS*, 419, L34
- Mosser, B., et al. 2012, *Astronomy and Astrophysics*, 540, 143
- Nataf, D. M., et al. 2012, *ArXiv e-prints*
- Nordström, B., et al. 2004, *A&A*, 418, 989
- Olsen, E. H. 1983, *A&AS*, 54, 55
- Olsen, E. H. 1984, *A&AS*, 57, 443
- Olsen, E. H. 1994a, *A&AS*, 104, 429
- Olsen, E. H. 1994b, *A&AS*, 106, 257
- Önehag, A., Gustafsson, B., Eriksson, K., & Edvardsson, B. 2009, *A&A*, 498, 527
- Pagel, B. E. J. 2009, *Nucleosynthesis and Chemical Evolution of Galaxies*
- Pagel, B. E. J., & Tautvaisiene, G. 1995, *MNRAS*, 276, 505

- Perryman, M. A. C., et al. 2001, *A&A*, 369, 339
- Pietrinferni, A., Cassisi, S., Salaris, M., & Castelli, F. 2004, *ApJ*, 612, 168
- Pilkington, K., et al. 2012, *MNRAS*, 425, 969
- Pinsonneault, M. H., An, D., Molenda-Żakowicz, J., Chaplin, W. J., Metcalfe, T. S., & Bruntt, H. 2012, *ApJS*, 199, 30
- Platais, I., Gosnell, N. M., Meibom, S., Kozhurina-Platais, V., Bellini, A., Veillet, C., & Burkhead, M. S. 2013, *AJ*, 146, 43
- Plavchan, P., Bilinski, C., & Currie, T. 2014, *PASP*, 126, 34
- Pont, F., & Eyer, L. 2004, *ApJ*, 351, 487
- Reddy, B. E., Lambert, D. L., & Allende Prieto, C. 2006, *MNRAS*, 367, 1329
- Reid, I. N., & Hawley, S. L. 2005, New light on dark stars : red dwarfs, low-mass stars, brown dwarfs
- Reimers, D. 1975, *Memoires of the Societe Royale des Sciences de Liege*, 8, 369
- Roederer, I. U., & Sneden, C. 2011, *AJ*, 142, 22
- Rosvick, J. M., & Vandenberg, D. A. 1998, *AJ*, 115, 1516
- Sandquist, E. L., et al. 2013, *ApJ*, 762, 58
- Savitzky, A., & Golay, M. J. E. 1964, *Analytical Chemistry*, 36, 1627
- Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, *ApJ*, 500, 525
- Schönrich, R., & Binney, J. 2009, *MNRAS*, 396, 203
- Schuster, W. J., & Nissen, P. E. 1988, *A&AS*, 73, 225

- Schuster, W. J., & Nissen, P. E. 1989, *A&A*, 221, 65
- Serenelli, A. M., Bergemann, M., Ruchti, G., & Casagrande, L. 2013, *MNRAS*, 429, 3645
- Silva Aguirre, V., et al. 2013, *ApJ*, 769, 141
- Silva Aguirre, V., et al. 2012, *ApJ*, 757, 99
- Silva Aguirre, V., et al. 2011, *ApJ*, 740, L2
- Skrutskie, M. F., et al. 2006, *AJ*, 131, 1163
- Snedden, C., Kraft, R. P., Guhathakurta, P., Peterson, R. C., & Fulbright, J. P. 2004, *AJ*, 127, 2162
- Soderblom, D. R. 2010, *ARA&A*, 48, 581
- Steinmetz, M., et al. 2006, *AJ*, 132, 1645
- Stello, D., Chaplin, W. J., Basu, S., Elsworth, Y., & Bedding, T. R. 2009, *Monthly Notices of the Royal Astronomical Society: Letters*, 400, L80
- Stello, D., et al. 2013, *ApJ*, 765, L41
- Stello, D., et al. 2011, *ApJ*, 739, 13
- Strömgren, B. 1963, *QJRAS*, 4, 8
- Strömgren, B. 1966, *ARA&A*, 4, 433
- Strömgren, B. 1987, in *NATO ASIC Proc. 207: The Galaxy*, ed. G. Gilmore & B. Carswell, 229
- Thygesen, A. O., et al. 2012, *A&A*, 543, A160
- Tinsley, B. M. 1979, *ApJ*, 229, 1046

- Twarog, B. A., Vargas, L. C., & Anthony-Twarog, B. J. 2007, *AJ*, 134, 1777
- Ulrich, R. K. 1986, *ApJ*, 306, L37
- van den Bergh, S. 1962, *AJ*, 67, 486
- Verner, G. A., et al. 2011, *MNRAS*, 415, 3539
- Wallerstein, G. 1962, *ApJS*, 6, 407
- Wang, W., Zhao, G., & Chen, Y. 2014, *Proc. IAU Symp.* 298, *Setting the Scene for Gaia and LAMOST*, Cambridge University Press
- Wang, Y., & Zhao, G. 2013, *ApJ*, 769, 4
- Weiss, A., & Schlattl, H. 2008, *Ap&SS*, 316, 99
- White, T. R., et al. 2013, *Monthly Notices of the Royal Astronomical Society*, 433, 1262
- Yang, S.-C., Sarajedini, A., Deliyannis, C. P., Sarrazine, A. R., Kim, S. C., & Kyeong, J. 2013, *ApJ*, 762, 3
- Yanny, B., et al. 2009, *AJ*, 137, 4377
- Yong, D., Grundahl, F., Johnson, J. A., & Asplund, M. 2008, *ApJ*, 684, 1159

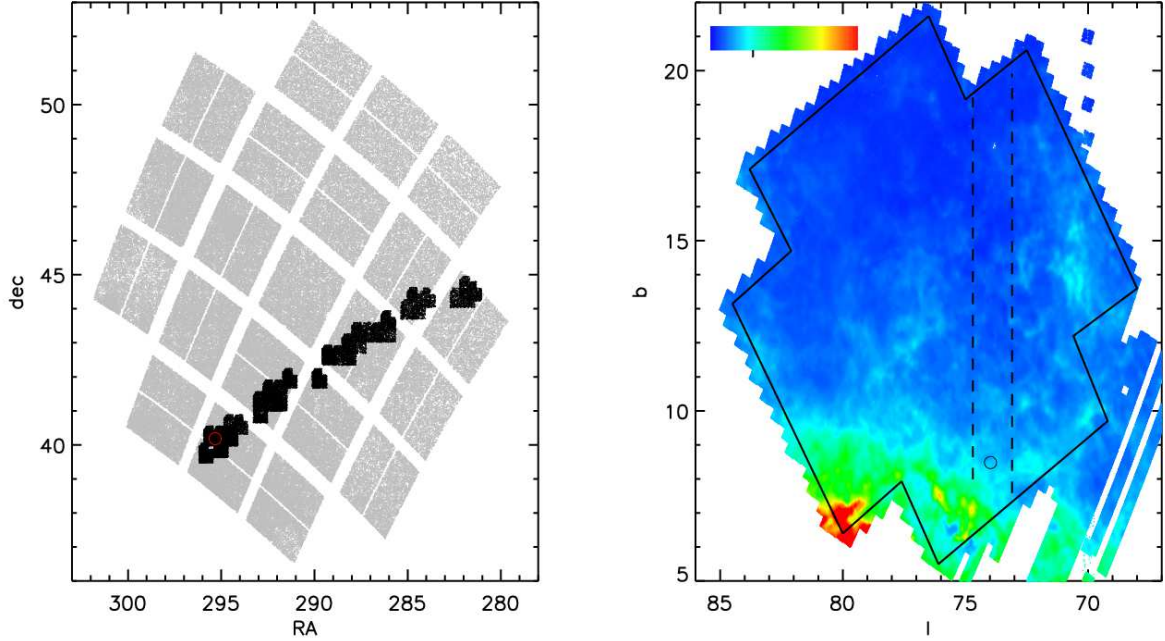


Fig. 1.— *Left panel:* The *Kepler* field as seen via the 42 CCDs on board of the spacecraft. Overplotted in black is the full sample of stars with *uvby* magnitudes measured during the first run of the SAGA survey. The circle marks the position of the open cluster NGC 6819. *Right panel:* *Kepler* field (defined with continuous black lines) plotted in Galactic latitude (b) and longitude (l) as seen in the Schlegel et al. (1998) map. Linear color code corresponds reddening in the range $0 < E(B - V) < 1$. The tick mark in the upper bar identifies $E(B - V) = 0.3$ which is the highest value in the Schlegel et al. (1998) map over our observed stripe. Vertical dashed lines mark the observed stripe, and the open circle indicates the position of NGC 6819.

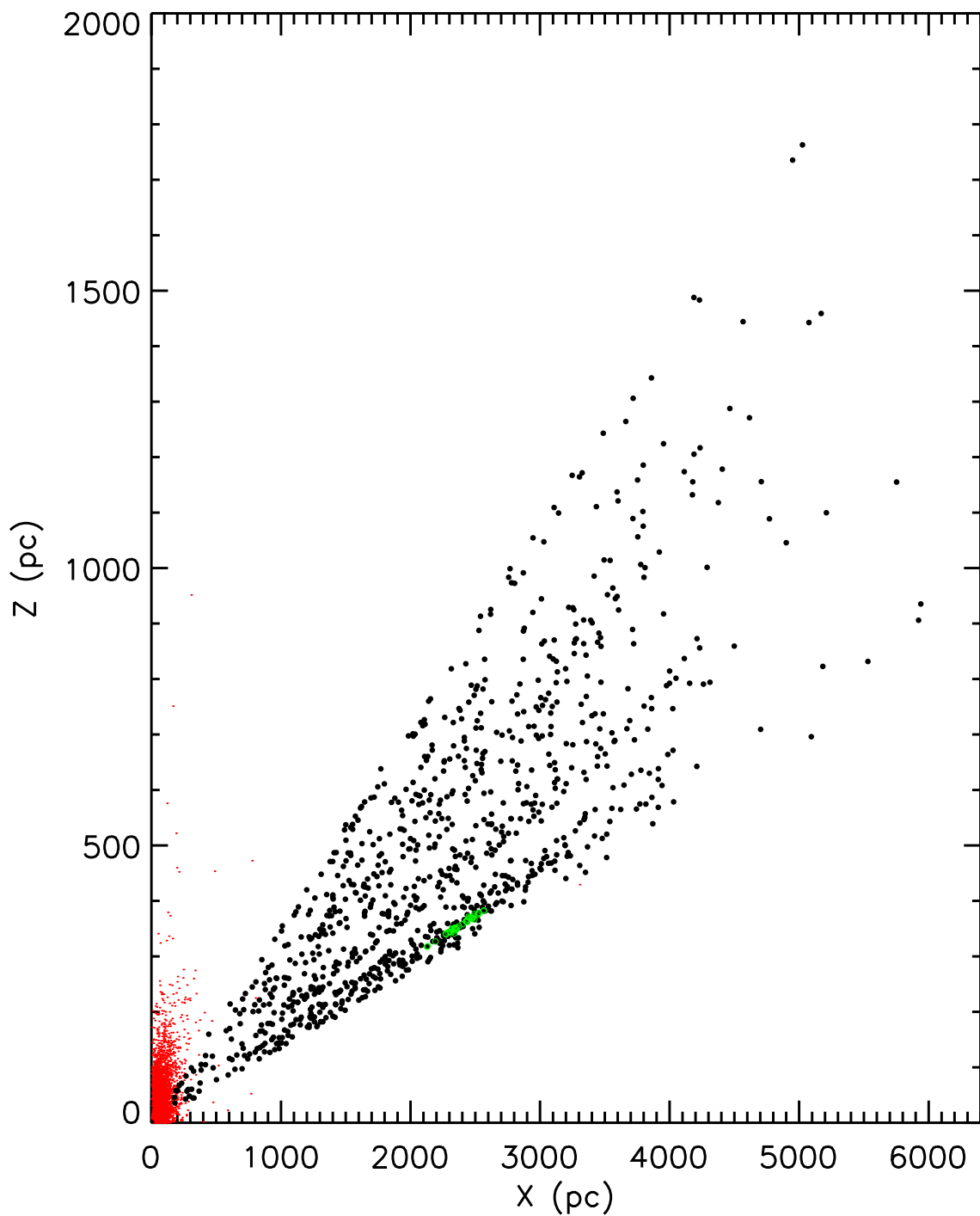


Fig. 2.— Distance distribution for all seismic targets currently in SAGA. Overplotted in red is the volume surveyed by the Geneva-Copenhagen Survey. Highlighted with green open circles are giants belonging to NGC 6819. Distances have been derived as described in Section 3.

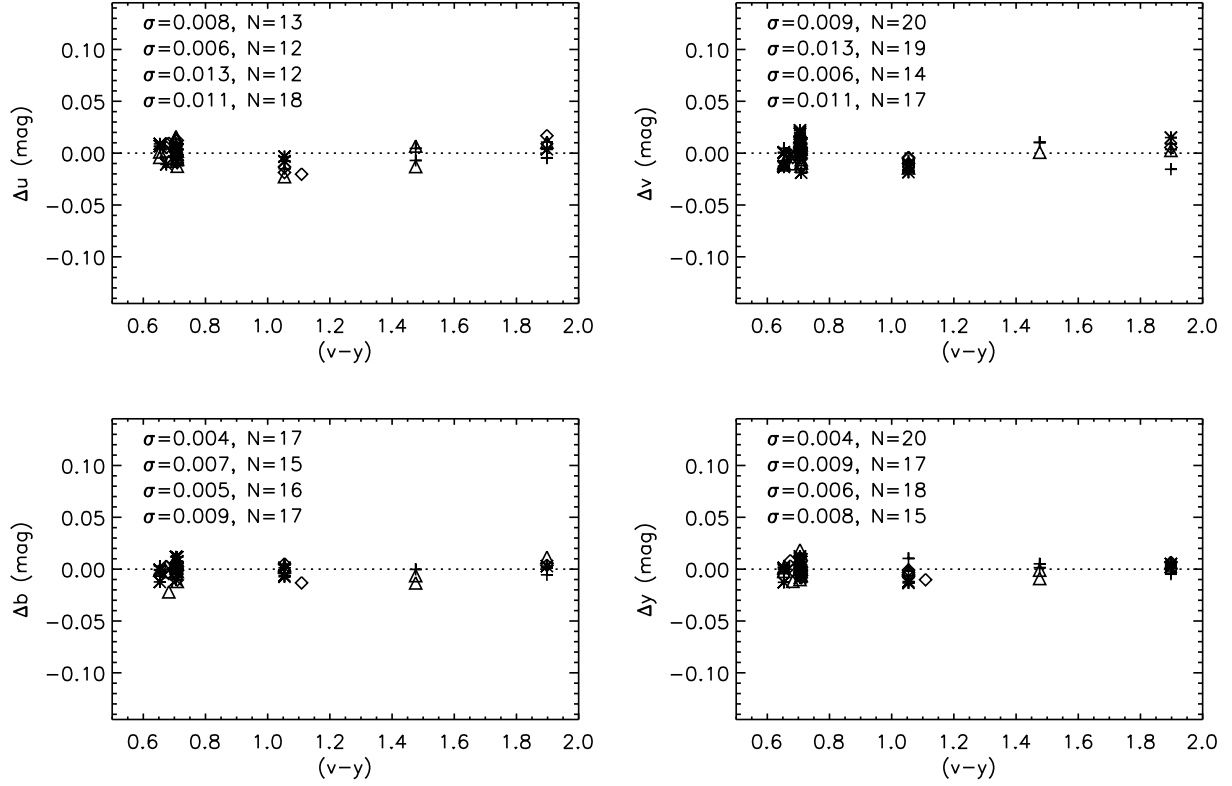


Fig. 3.— Residuals of the standard stars (calibrated minus standard) as function of their $(v-y)$ color. The number of points (N) and the scatter (σ) for each photometric night (different symbol for each night) is indicated.

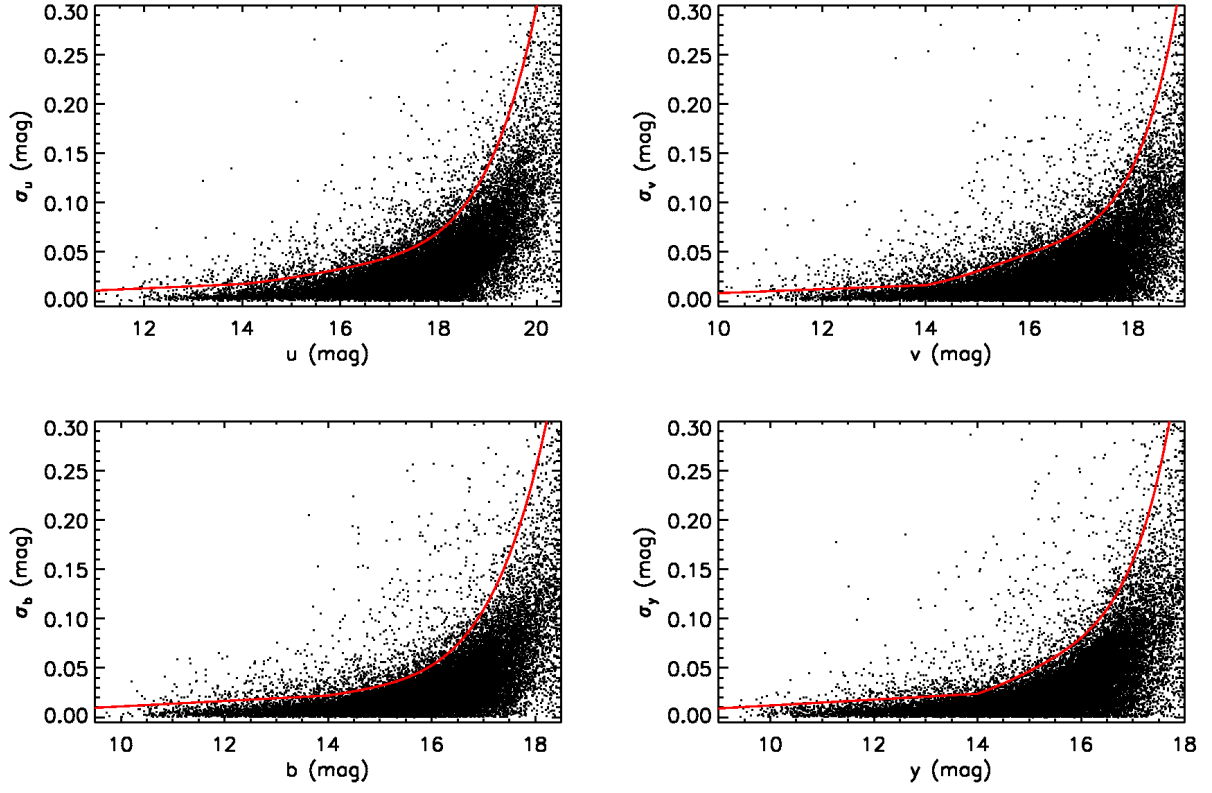


Fig. 4.— Final errors in u, v, b and y photometry. Stars above the continuous ridge-lines are labelled in the analysis as explained in Section 2.3.

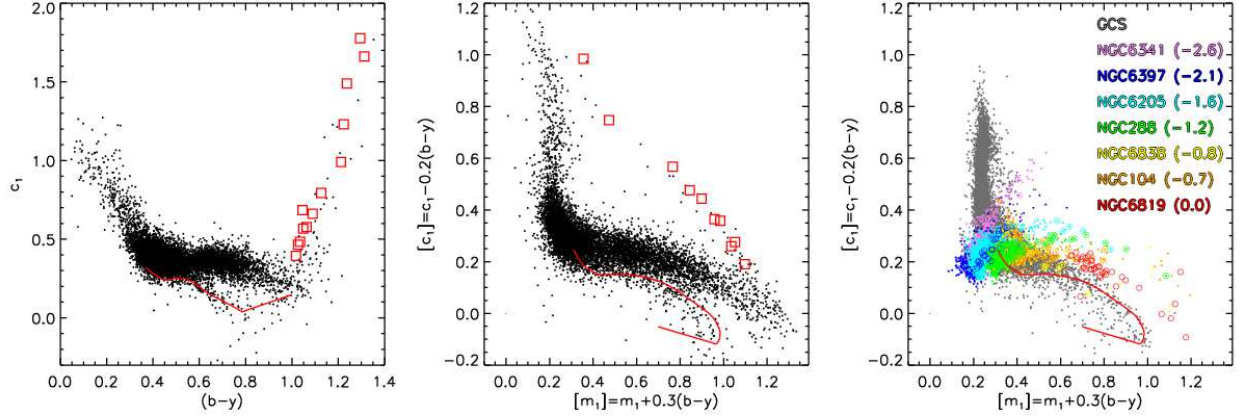


Fig. 5.— *Left panel:* c_1 vs. $(b - y)$ diagram for stars in our sample with $y < 15$ mag and photometric errors below ridge-lines of Figure 4. Open squares are cool M giants, while the continuous line represents the dwarf sequence, both from Olsen (1984). *Central panel:* same as previous, but for reddening-free indices $[c_1]$ vs. $[m_1]$. *Right panel:* reddening-free indices for dwarfs and subgiants from the GCS as well as for a number of RGB stars in stellar clusters (metallicities in parenthesis), all standardized to the system of Olsen. Open circles are stars with spectroscopic $[\text{Fe}/\text{H}]$ used for our giants metallicity calibration.

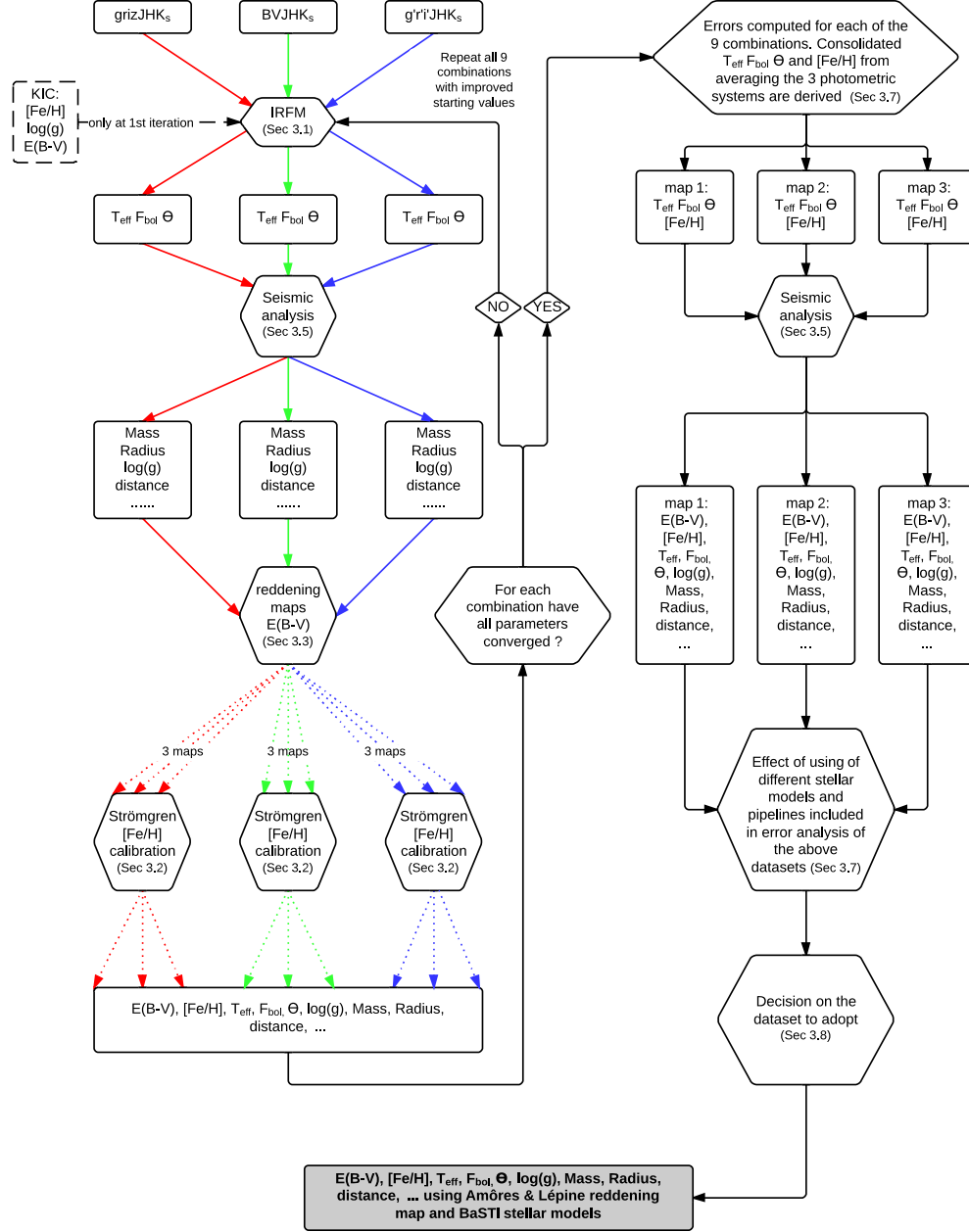


Fig. 6.— Flow chart of the procedure adopted to intertwine the derivation of classical and seismic parameters. Reddening maps 1, 2, and 3 are the Drimmel et al. (2003) and the two flavors of the Amôres & Lépine (2005).

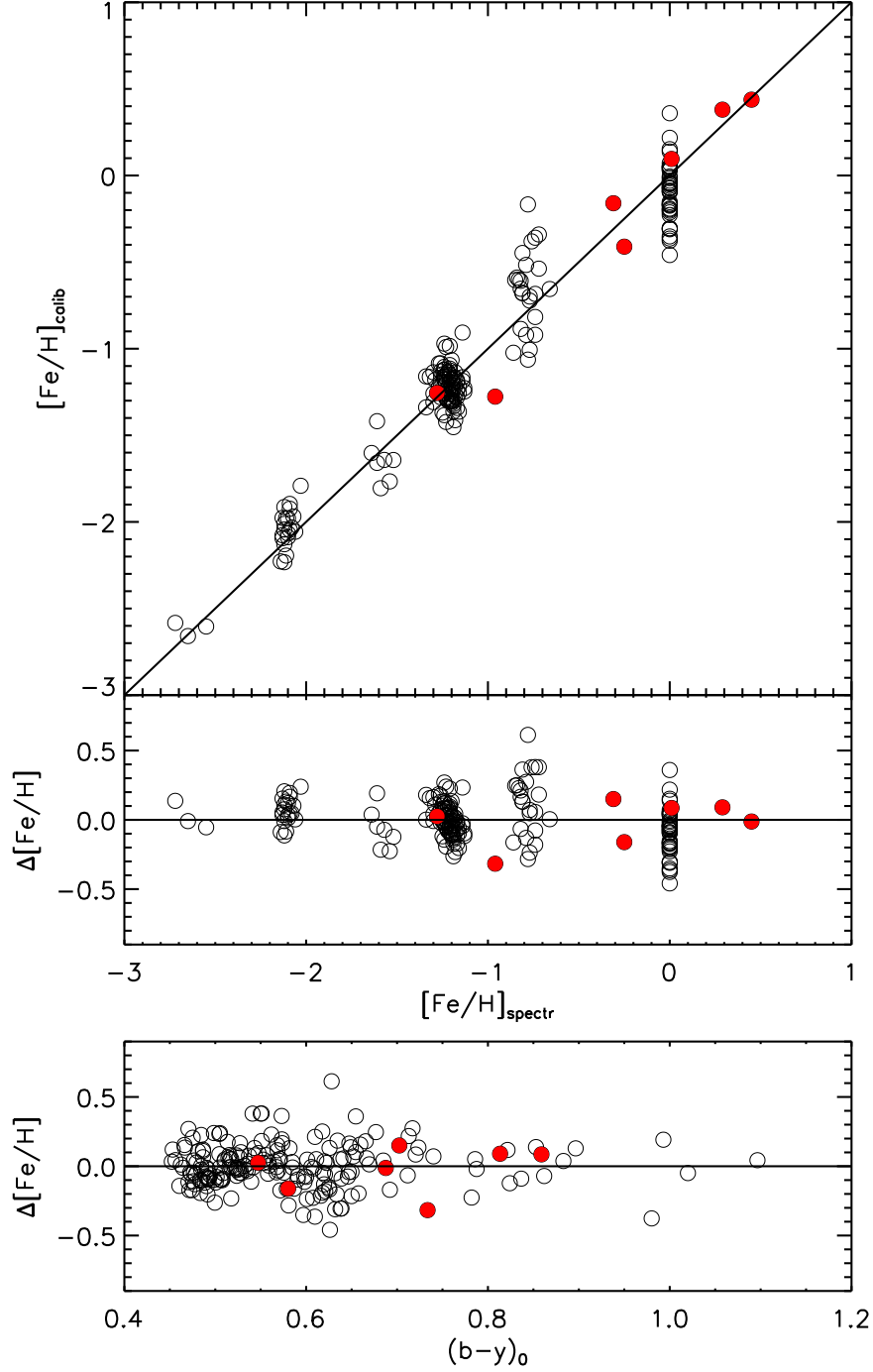


Fig. 7.— *Top panel*: spectroscopic versus photometric metallicities obtained using the calibration presented in Section 3.2 for giants. Open circles are giants in clusters, while filled circles are field giants from Thygesen et al. (2012). *Middle panel*: same as above, but showing residuals (photometric minus spectroscopic). *Bottom panel*: same as in previous one, but as function of dereddened $(b - y)_0$, which is a proxy of the effective temperature.

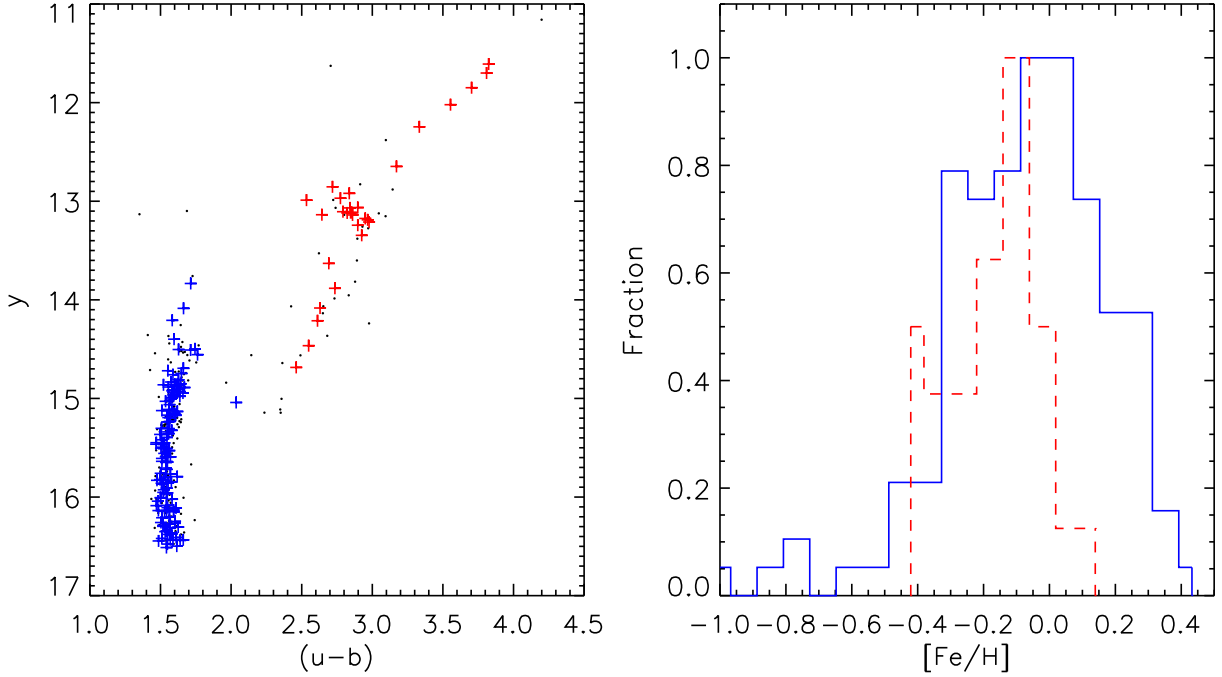


Fig. 8.— *Left panel:* NGC 6819 color-magnitude diagram. Only single-stars having radial velocity membership probabilities higher than 80% in Hole et al. (2009) are shown. Highlighted in red (blue) are giant (main-sequence) stars within $\simeq 7$ arcmin from the cluster centre and with photometric errors below the ridge-lines of Figure 4. *Right panel:* Strömgren metallicity histogram for the same dwarfs (continuous) and giants (dashed line) highlighted in the left panel. The difference between the peaks of the metallicity distributions of dwarfs and giants (0.08 dex) has been corrected as explained in Section 3.2.

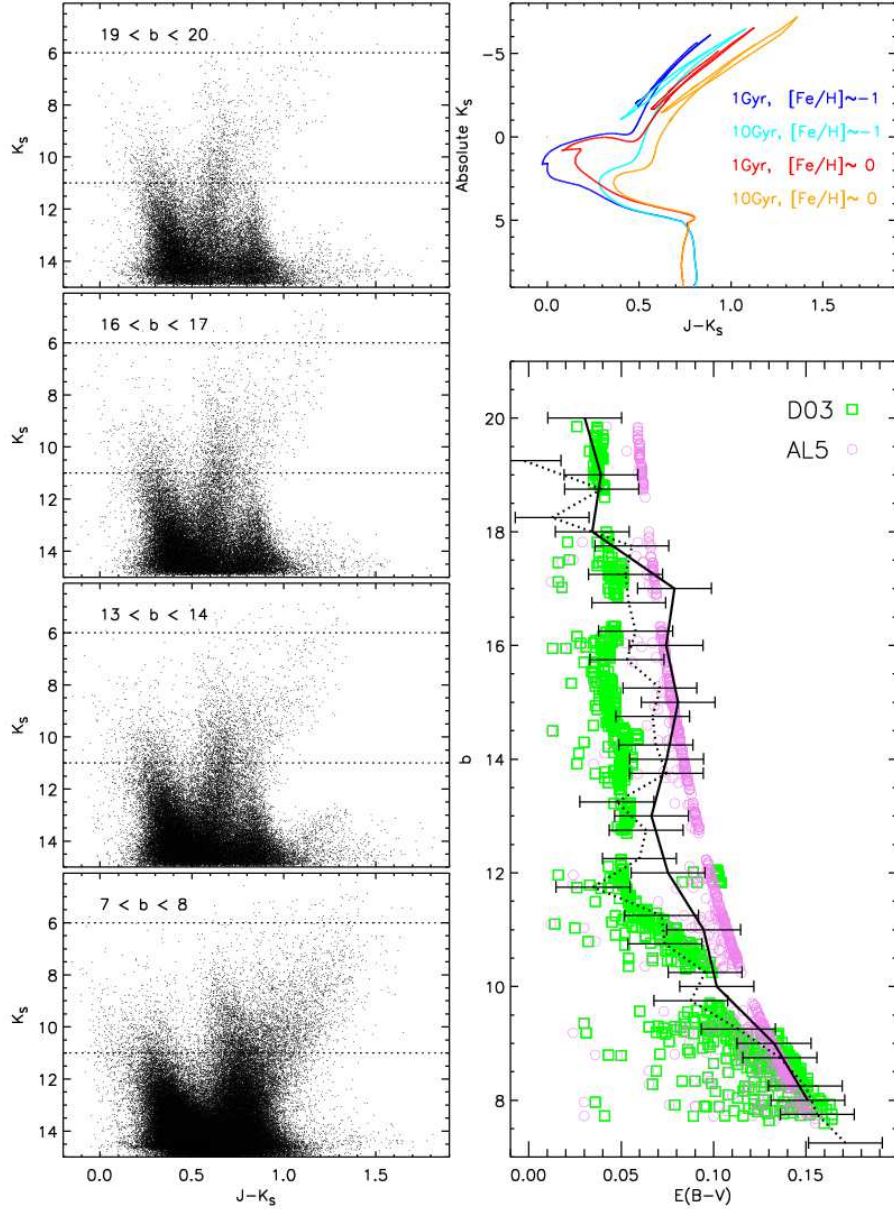


Fig. 9.— *Left panels*: observed $J - K_S$ vs. K_S diagram for stars with good 2MASS photometry at selected intervals in Galactic latitude b , and with longitude $|l - 72.5^\circ| < 2.5^\circ$. Dotted horizontal lines indicate the K_S magnitude range used to empirically derive reddening (see text for details). *Top right*: BaSTI isochrones in the 2MASS system for two values of metallicity and age (Pietrinferni et al. 2004). *Bottom right*: reddening derived using the procedure described in Section 3.3, sampling the 2MASS color-apparent magnitude diagram each 0.5° (dotted) or 1° (continuous lines), after scaling to the $E(B - V)$ of NGC 6819. Open circles and squares are reddening values derived for our *Kepler* stars using the Amôres & Lépine 2005 (AL05) and Drimmel et al. 2003 (D03) maps.

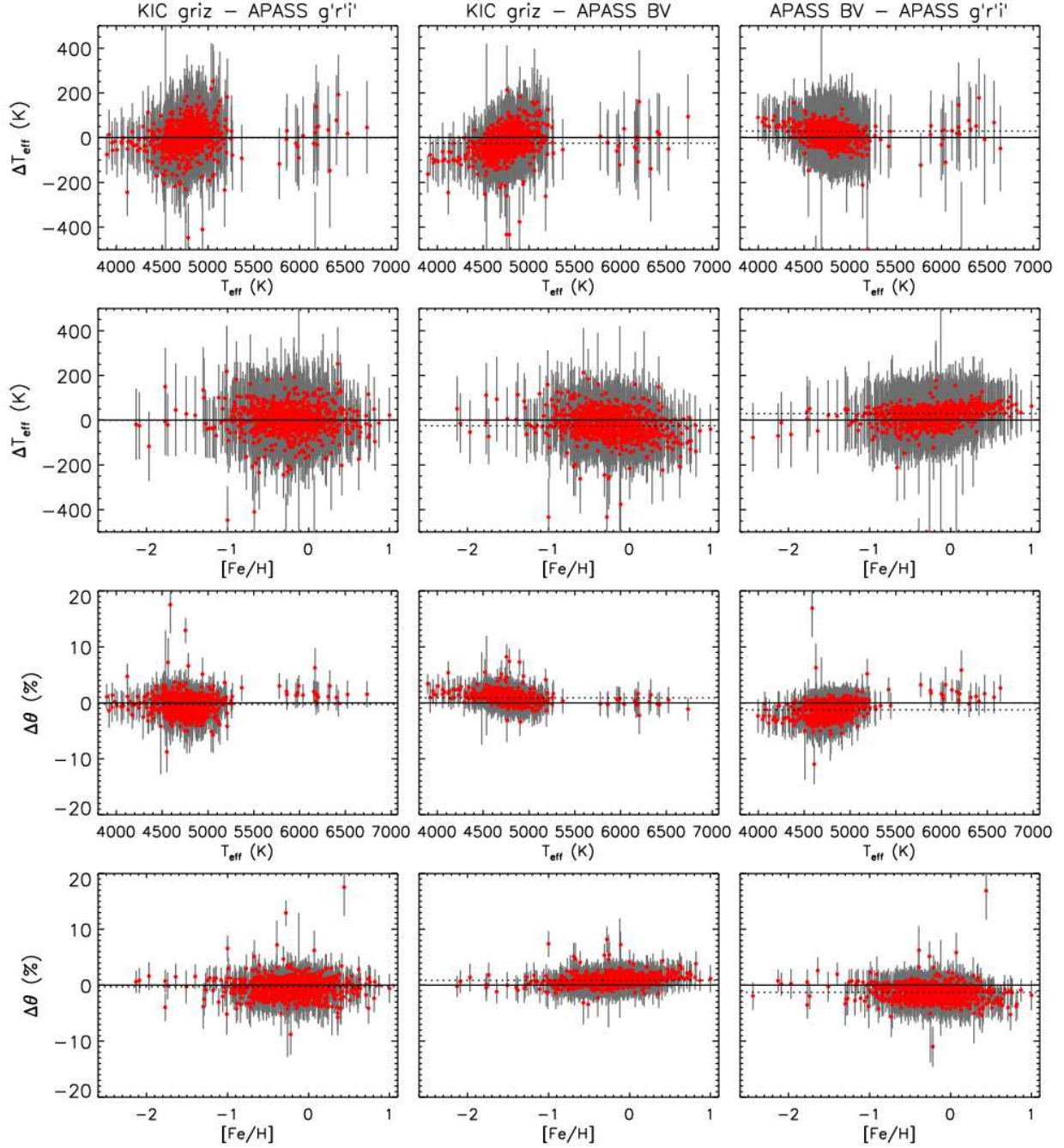


Fig. 10.— Comparison between T_{eff} (first and second rows) and θ (third and fourth rows) derived implementing different optical photometric systems in the IRFM (first, second and third column), with corresponding error bars. In all instances the same reddening map is used (see discussion in Section 3.7) although adopting a different one barely changes this comparison. Dotted lines represent the median differences.

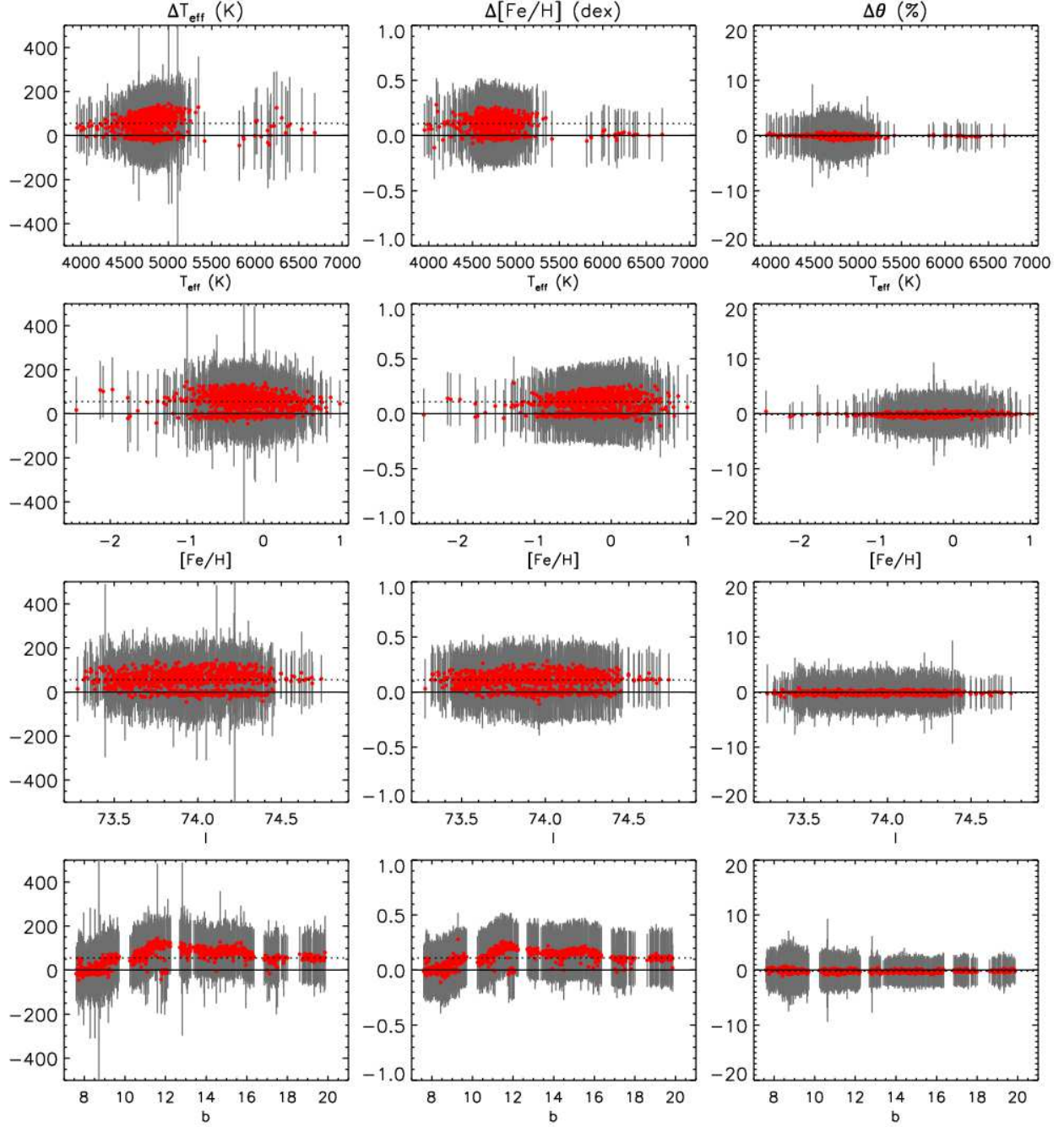


Fig. 11.— Comparison between the consolidated set of effective temperatures (first column), metallicities (second column) and angular diameters (third column) derived using two different reddening maps (Amôres & Lépine 2005 minus Drimmel et al. 2003). Stars showing almost no difference are those located at Galactic latitudes $b \simeq 8.5$, where both maps are anchored at the $E(B - V)$ of NGC 6819. Dotted line is the median difference.

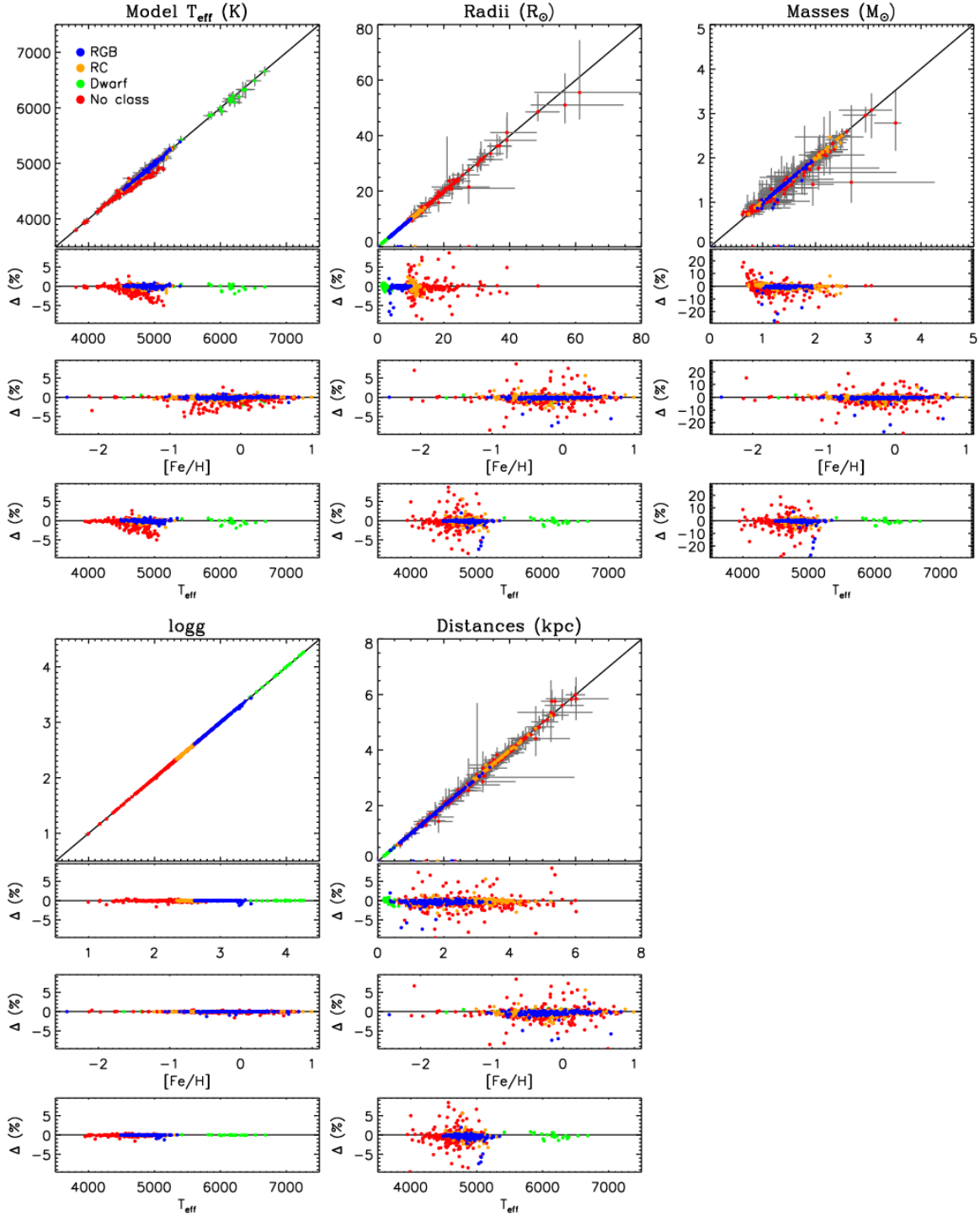


Fig. 12.— Difference in the classical plus seismic quantities derived when using the Amôres & Lépine (2005, horizontal axis) or Drimmel et. al (2005, vertical axis) reddening maps. The fractional difference is shown as function of the parameter investigated, as well of the consolidated T_{eff} and $[\text{Fe}/\text{H}]$. Different colors identify stars with different seismic classification.

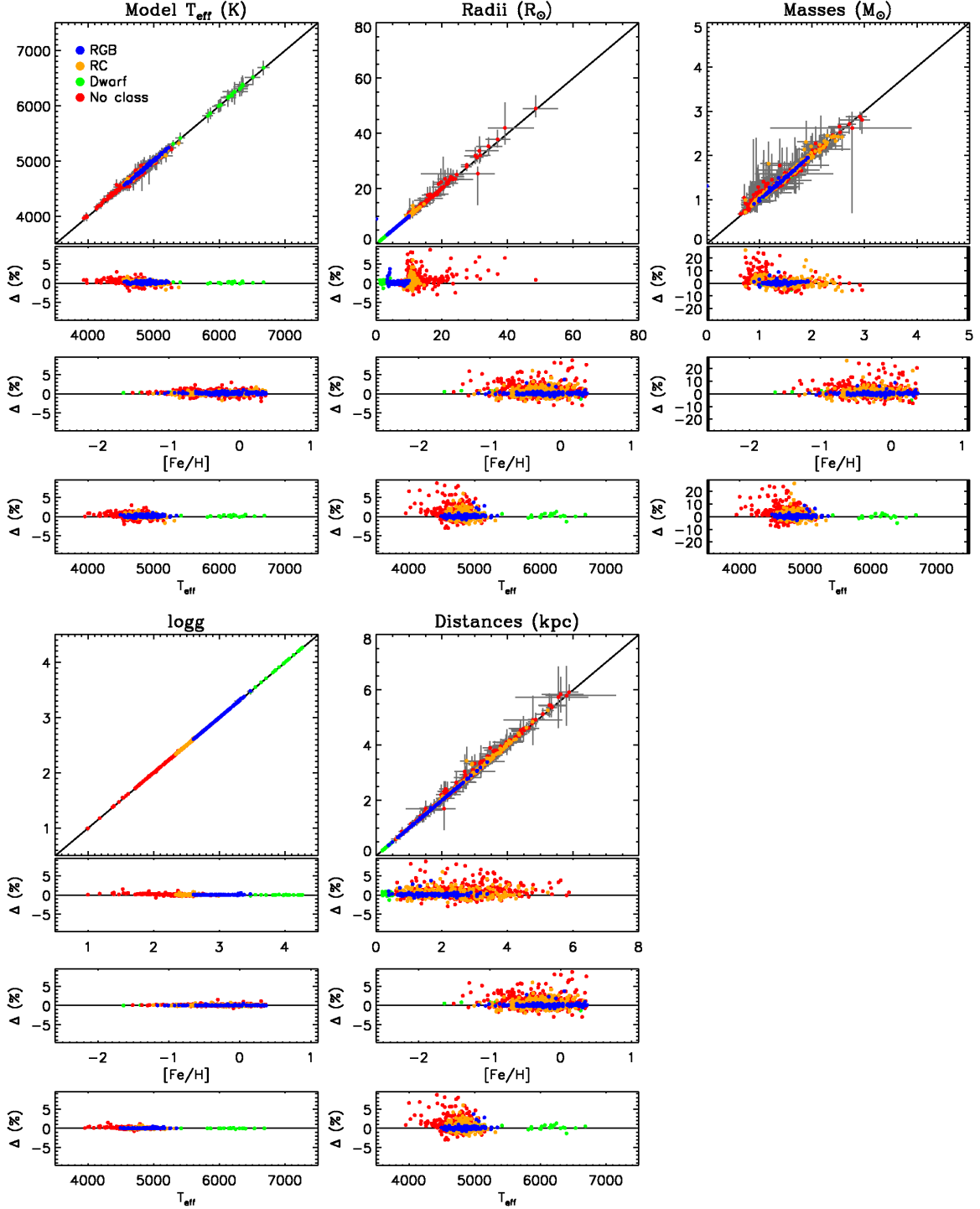


Fig. 13.— Same as Figure 12, but comparing the effect of using a Bayesian (horizontal) or a Monte-Carlo (vertical) scheme with the BaSTI models to derive seismic parameters. The same reddening map is assumed in both cases.

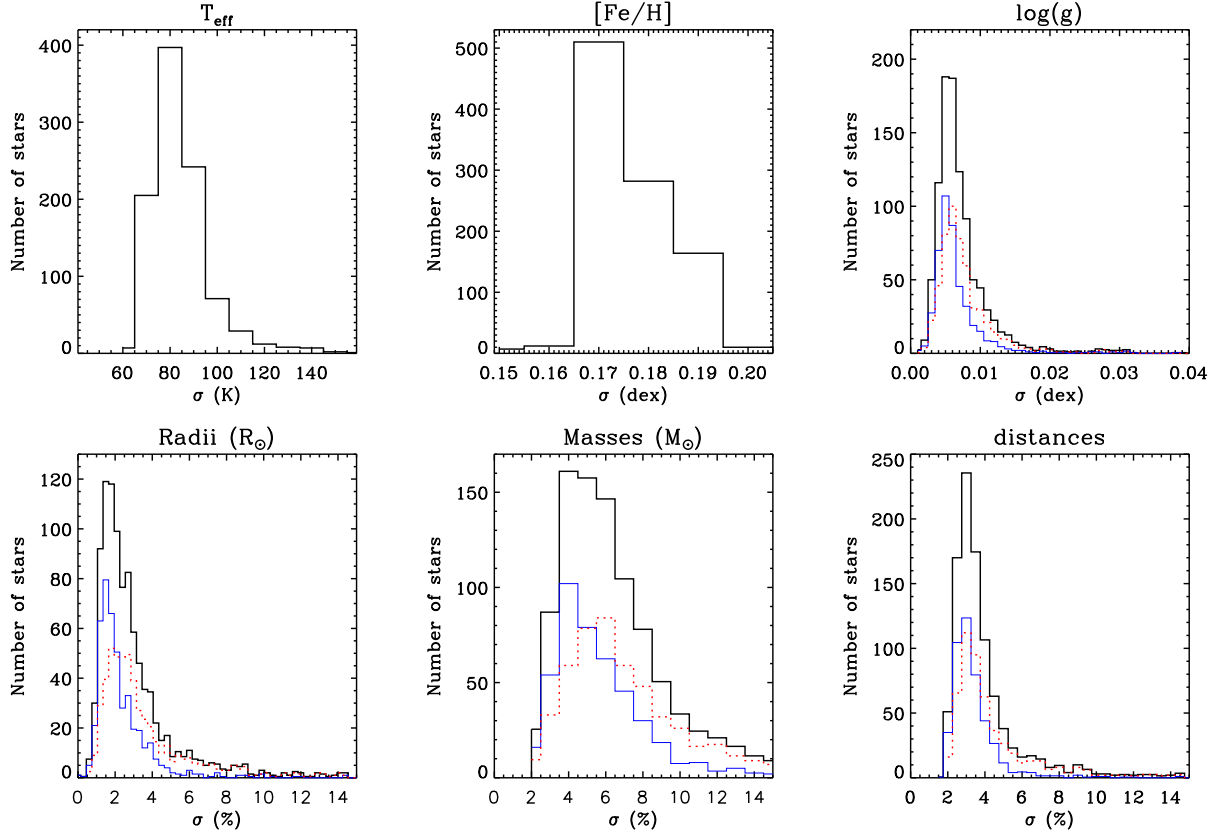


Fig. 14.— Final error distributions of the main stellar parameters derived. For the asteroseismic quantities, the overall distribution is also split into stars with (blue) and without (red) evolutionary phase classification (Section 3.4).

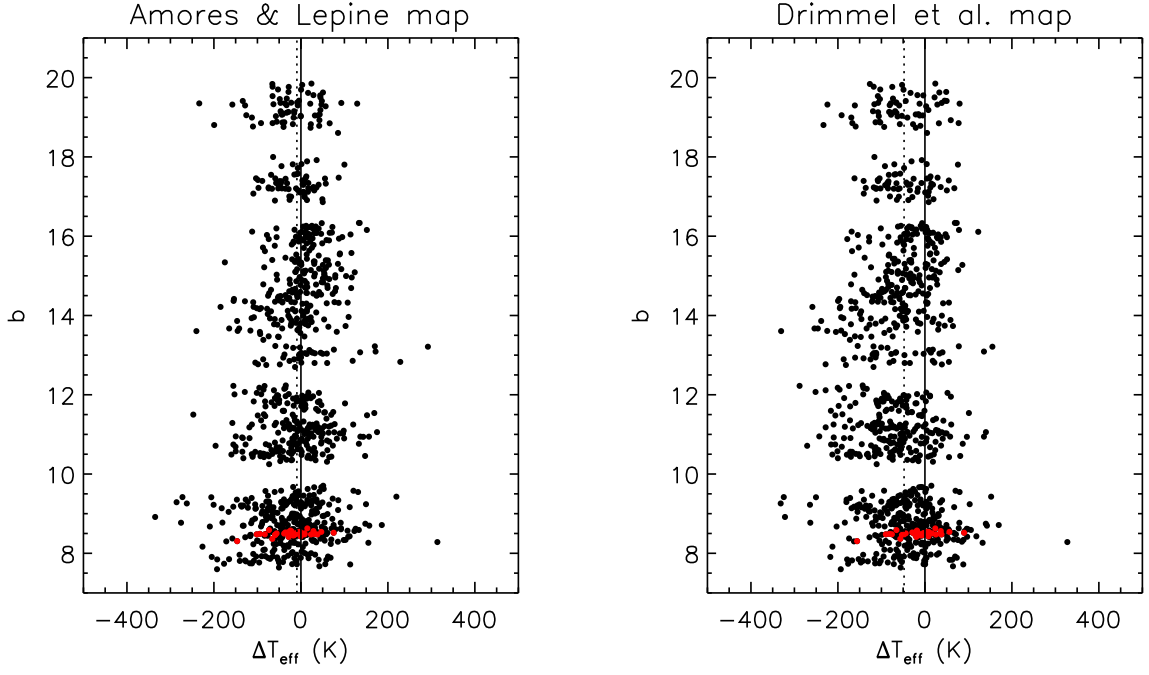


Fig. 15.— Difference between T_{eff} obtained from the IRFM and from theoretical modelling for each star (IRFM minus models) as function of Galactic latitude b for two different reddening maps, as indicated. Dotted line is the median difference. At low b , stars belonging to NGC 6819 and used to calibrate both reddening maps are highlighted (see Section 3.3).

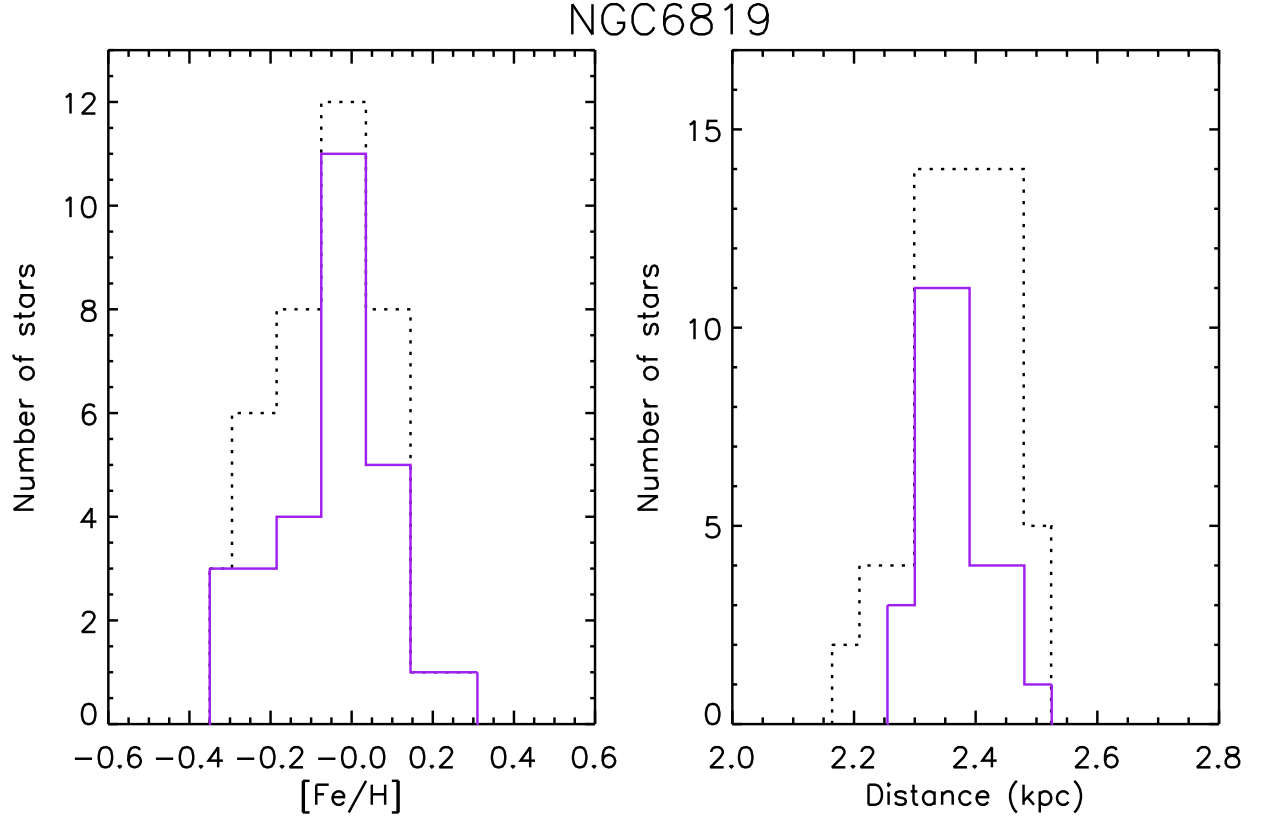


Fig. 16.— Parameters determined for giants in the open cluster NGC 6819, selected according to the seismic classification of Stello et al. (2011). *Left panel:* metallicities for all stars (dotted line) or retaining only stars with good photometric quality flag (continuous line, Section 2.3). *Right panel:* distances for the same stars. Now, dotted line refers to all stars, while continuous line is for stars having certain seismic classification (Section 3.4).

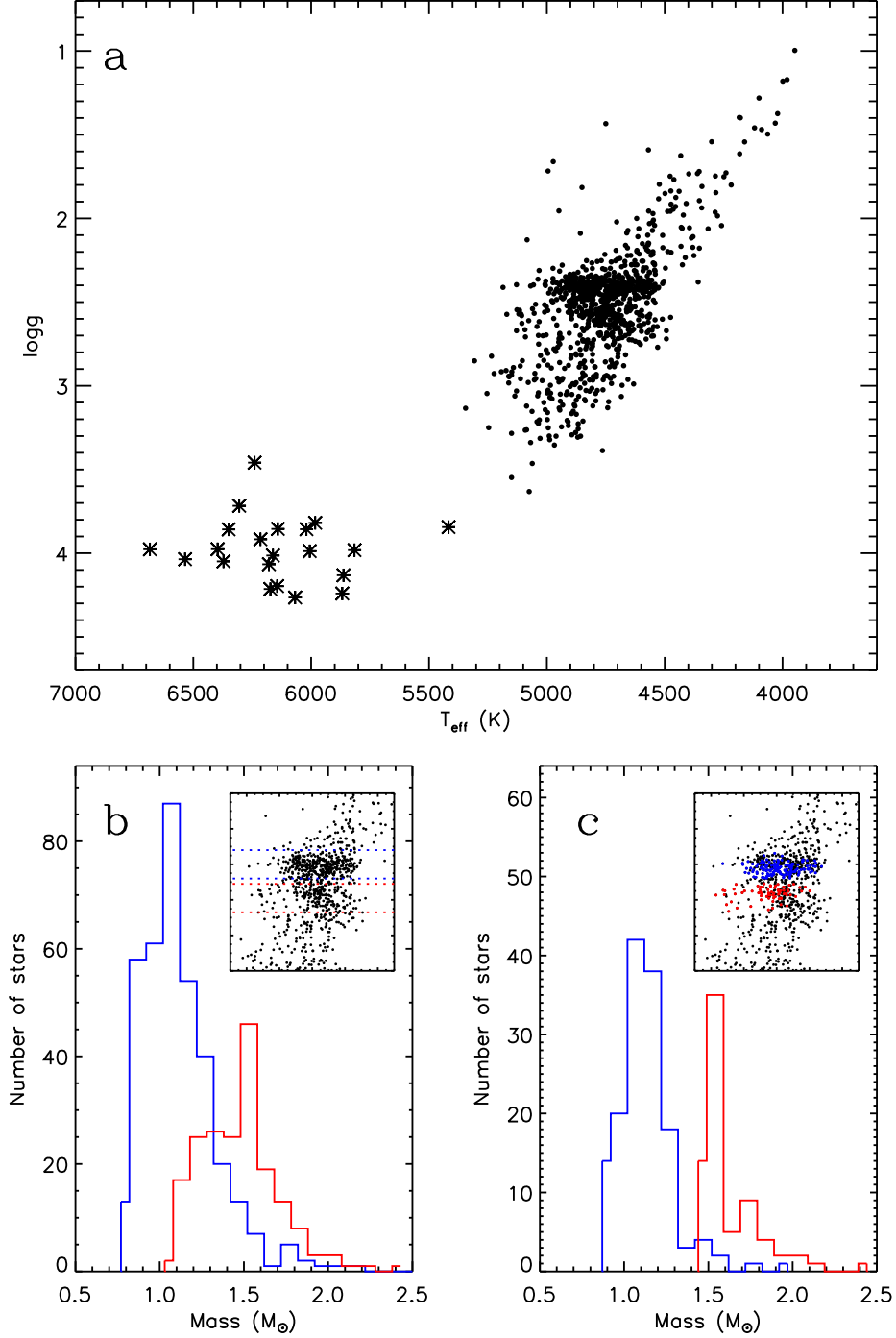


Fig. 17.— *Panel a*: T_{eff} and $\log g$ for our sample of stars. Asterisks/circles identify stars for which we used the dwarfs/giants metallicity calibrations (Section 3.2). *Panel b*: first (blue) and secondary (red) clump dissection based only on $\log g$ selection (range indicated by dotted lines in the upper inset) and corresponding histogram for their mass distribution. *Panel c*: same as previous panel, but retaining only stars with certain clump classification.

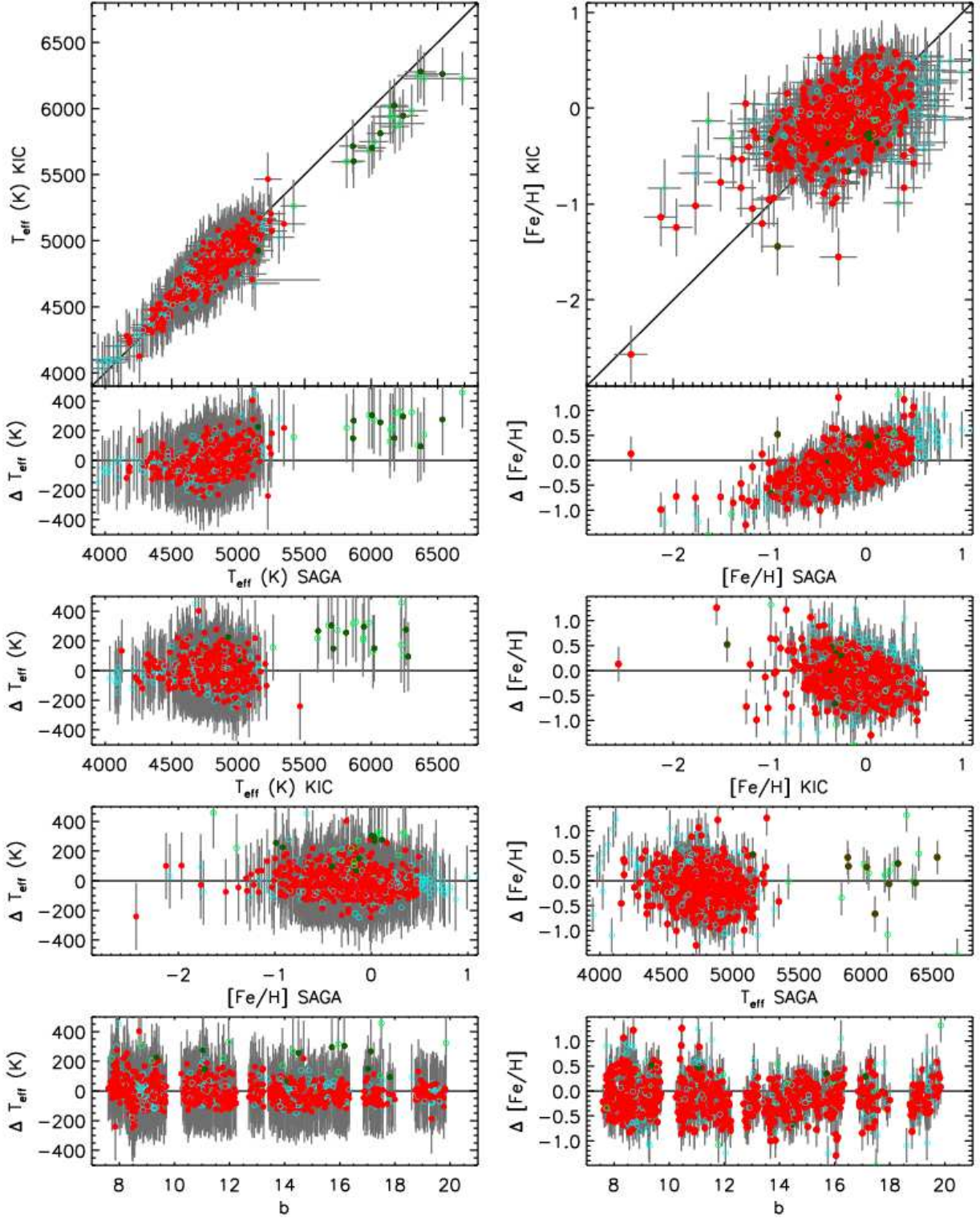


Fig. 18.— Comparison between T_{eff} (first) and $[\text{Fe}/\text{H}]$ (second column) determined for stars in the SAGA and KIC ($\Delta = \text{SAGA} \text{ minus KIC}$). Filled-red/open-cyan (filled-dark/open green) circles identify giants (dwarfs) with more certain/uncertain Strömgen labels (see Section 3.2).

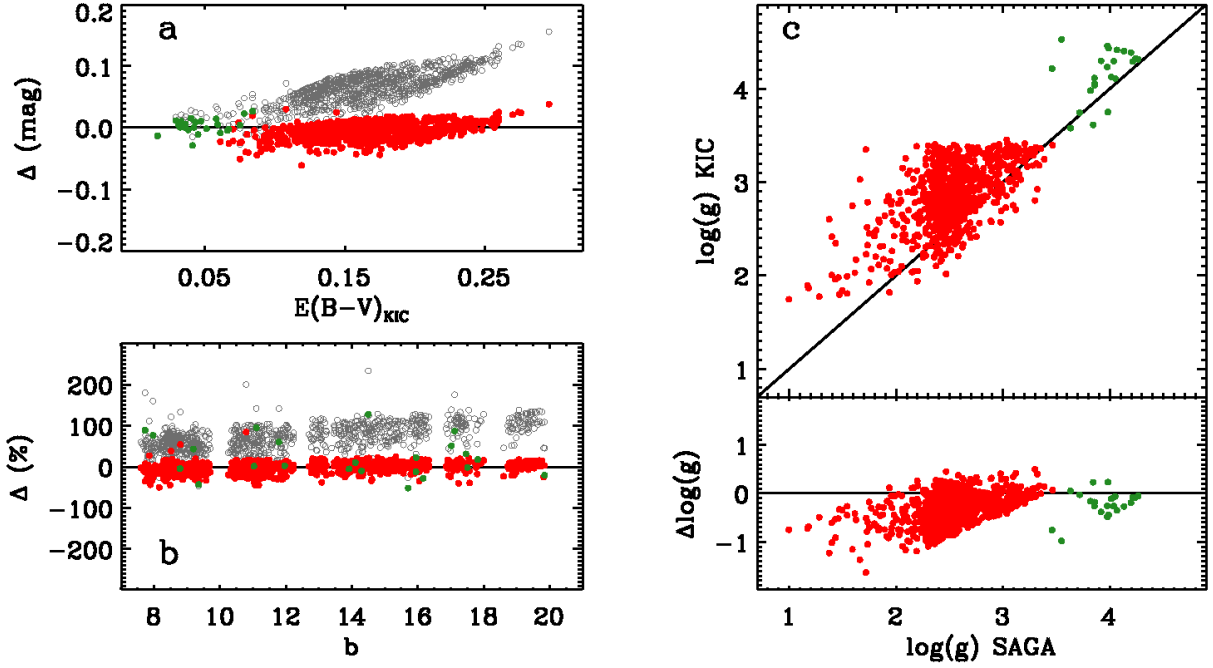


Fig. 19.— *Panel a*: comparison between the color excess $E(B - V)$ in the KIC and SAGA (gray circles, KIC minus SAGA). Colored circles (green for dwarfs, red for giants) highlight the same comparison after correcting the KIC reddening according to Equation 9. *Panel b*: same as in panel a, but showing the percent difference (KIC/SAGA) as function of Galactic latitude. *Panel c*: comparison between $\log g$ in the KIC and asteroseismic values in SAGA.

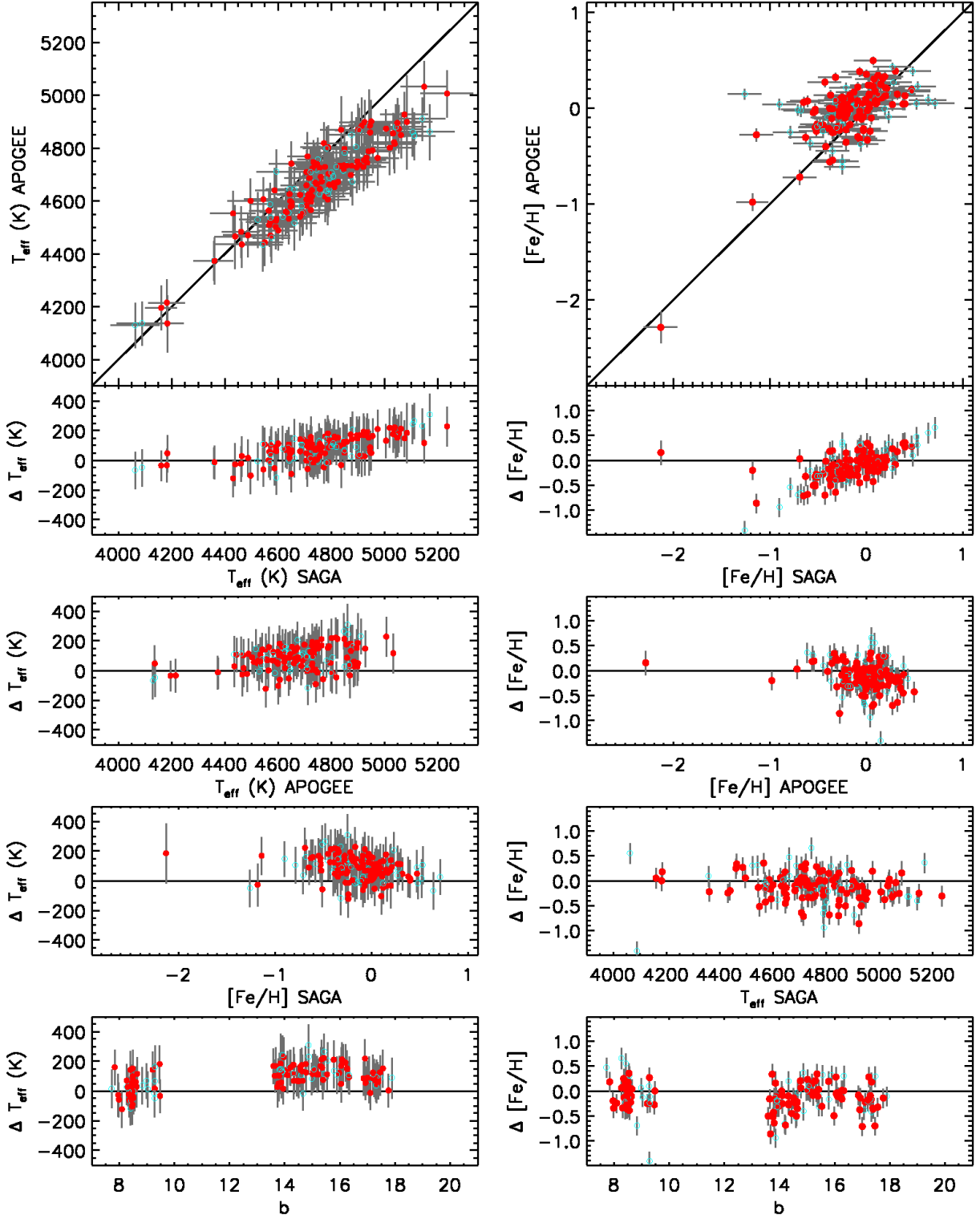


Fig. 20.— Same as Figure 18 but comparing giants in SAGA with APOGEE ($\Delta = \text{SAGA}$ minus APOGEE).

Table 1. SAGA Asteroseismic Catalog Format

Column	Format	Description
1	A8	KIC ID
2	F6.1	Frequency of maximum oscillations power ν_{\max} (μHz)
3	F6.1	Error in ν_{\max} (μHz)
4	F7.2	Large frequency separation $\Delta\nu$ (μHz)
5	F7.2	Error in $\Delta\nu$ (μHz)
6	F5.2	Strömgren [Fe/H]
7	F5.2	Error in Strömgren [Fe/H]
8	F6.0	T_{eff} from the IRFM
9	F6.0	Error in T_{eff}
10	F7.2	Stellar radius (R_{\odot})
11	F7.2	Upper error in stellar radius
12	F7.2	Lower error in stellar radius
13	F7.2	Stellar mass (M_{\odot})
14	F7.2	Upper error in stellar mass
15	F7.2	Lower error in stellar mass
16	F6.3	Surface gravity
17	F6.3	Upper error in surface gravity
18	F6.3	Lower error in surface gravity
19	F10.7	Stellar density (ρ_{\odot})
20	F10.7	Upper error in stellar density
21	F10.7	Lower error in stellar density

Table 1—Continued

Column	Format	Description
22	F6.0	Distance from the Sun (pc)
23	F6.0	Upper error in distance
24	F6.0	Lower error in distance
25	A5	Asteroseismic classification
26	I1	Metallicity flag
27	I1	Strömgren photometry flag
28	F5.3	Strömgren $(b - y)$ index
29	F5.3	Strömgren m_1 index
30	F5.3	Strömgren c_1 index